25,432/B/1

2

3 — 23

[illegible] 21/11/5

92

12400

Digitized by the Internet Archive
in 2018 with funding from
Wellcome Library

https://archive.org/details/b30537563_0002

Mathematical ELEMENTS OF *Natural Philoſophy*, CONFIRMED BY EXPERIMENTS:

OR AN INTRODUCTION TO *Sir* Iſaac Newton's *Philoſophy*.

Written in LATIN,

By WILLIAM-JAMES 'S GRAVESANDE,

Doctor of Laws and Philoſophy.

Profeſſor of Mathematics and Aſtronomy at *Leyden*,
and Fellow of the Royal Society of *London*.

Tranſlated into ENGLISH

By J. T. DESAGULIERS, LL. D.

Fellow of the Royal Society, and Chaplain to his Grace the Duke of CHANDOS.

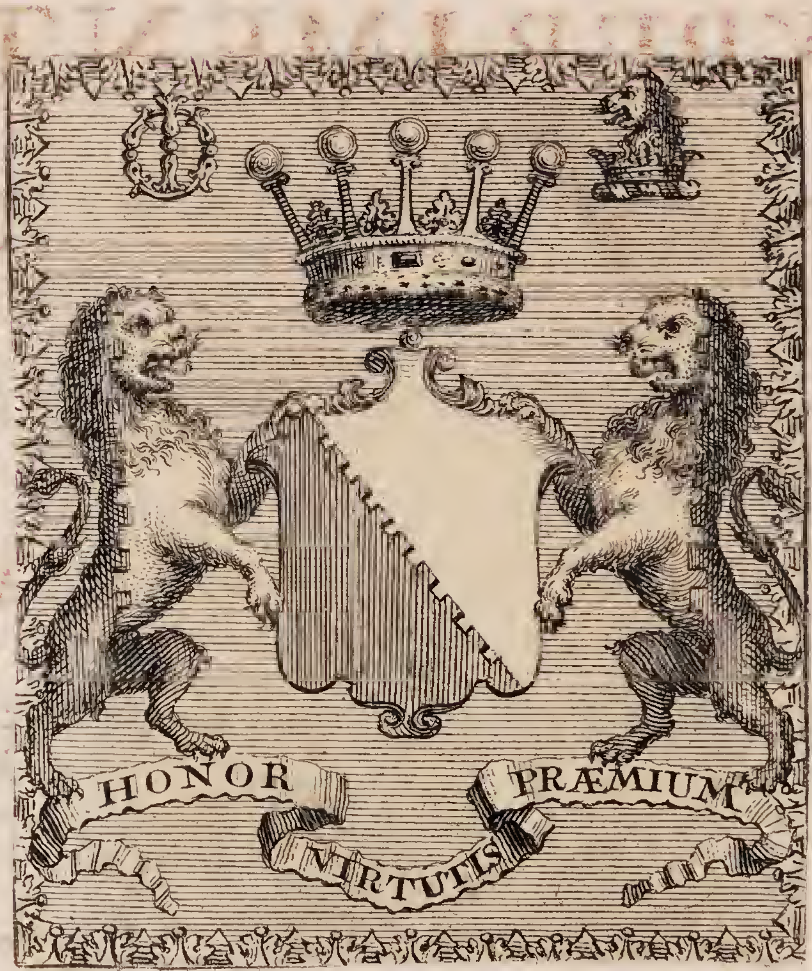
The Second VOLUME.

LONDON:

Printed for J. SENEX, at the *Globe* in *Salisbury-Court*,
and W. TAYLOR, at the *Ship* and *Black-Swan* in
Pater-Noſter-Row. MDCCXXI.

12700

WELLCOME
HISTORICAL
MEDICAL
LIBRARY


HONOR
VIRTUTIS
PRÆMIUM

TO THE

Moſt Noble and Right Honourable

THOMAS

Lord *PARKER*,

Baron of *Macclesfield*,

Lord HIGH-CHANCELLOR
of *GREAT-BRITAIN*, &c.

My LORD,

IF whilſt Your Lordſhip's Hours are taken up with an Employment of the greateſt Fatigue as well as the higheſt Honour, there can be any Time allow'd for Recreation, your Lordſhip makes that Your Diverſion, which few can attain to without painful Application and laborious Study. To become a skilful Mathematician and a ſound Philoſopher, and at the ſame time ſhine in other Parts of Learning, requires a great and extenſive Genius: But to lead a Life of Buſineſs, and be eminent in the Law, where Reputation is only got by conſtant Practice as well as Brightneſs of Parts: And yet, in thoſe few Minutes of Leiſure that are allow'd to breath in, and are, as it were, ſtol'n from Sleep; to play with all the Intricacies of Lines and Numbers, to view and underſtand the Syſtem of the World, the Proportion, Symmetry, and Harmony of its ſeveral Parts; to be acquainted with all the Experiments of Conſequence that have been made, and be able to contrive new ones as uſeful as inſtructive: was only reſerv'd to Men of uncommon Capacities, and to none in ſo eminent a Degree as to your Lordſhip.

The Honour I have had of being admitted into your Lordſhip's Converſation,

tion, has given me an Opportunity to know which of the Mathematical Sciences are chiefly lik'd by you: And as *Aſtronomy* and *Opticks* ſeem to have the Preference, I thought this Tranſlation of Dr. *s'Graveſande*'s Second Volume wou'd not be unacceptable.

Here you have the Principles of the common Optics reduc'd into a ſmall Compaſs, and confirm'd by new Experiments of the Author's own Invention: A fine Application of the Action of Electric Bodies to diſcover the Nature of Fire: And Sir ISAAC NEWTON's Doctrine of Light and Colours prov'd, by the moſt conſiderable of his Experiments, which Dr. *s'Graveſande* performs with an Apparatus very ingeniouſly contriv'd, and nicely expreſs'd by curious Figures. The laſt Part of this Volume not only leads a Beginner gradually on from the moſt ſimple to underſtand the moſt difficult *Phænomena* of *Aſtronomy*; but gives ſuch a phyſical Account of the Celeſtial Motions as muſt be fully ſatisfactory to the beſt Geometricians. There your Lordſhip will ſee with Pleaſure, that that there are Profeſſors abroad who underſtand the PRINCIPIA; and have ſo juſt a Value for that excellent Book, as to take Pains to propagate the wonderful Truths which it demonſtrates, ſo as to make them plain to ſuch Philoſophers as are not yet able to go thro' all the difficult Propoſitions from whence they are deduc'd. But I will detain your Lordſhip no longer, either from the important Buſineſs of your Station, or the pleaſing Truths of the Author, than while I beg leave to ſubſcribe myſelf,

MY LORD,

Your Lordſhip's

moſt Oblig'd,

moſt Obedient, and

moſt Humble Servant,

J. T. DESAGULIERS.

The AUTHOR'S PREFACE.

I *Spoke of the Method of reaſoning to be uſed in Natural Philoſophy, in the firſt Chapter of the firſt Volume, and in the Preface endeavour'd to vindicate the goodneſs of the Method I have follow'd. There are ſeveral remarkable Specimens of this Method in the preſent Volume, which evidently ſhew Sir* Iſaac Newton's *great ſuperiority of Genius above all other Philoſophers.*

Before him, Naturaliſts were in the Dark in numberleſs things relating to Light, and eſpecially to Colours. For inſtance, who ever ſuſpected before, that the Opacity of Bodies depended upon their Interſtices, ſo that a Body becomes tranſpatent, when theſe Interſtices are fill'd with a Medium of the ſame Denſity as the Particles of the Body itſelf.

His Account of the Planetary Syſtem, and particularly of the Motion of the Moon, is not leſs worthy of eternal Praiſes, being likely to carry Aſtronomy to a greater pitch of Perfection, than the niceſt Obſervations alone cou'd poſſibly do.

do. For if a Man is acquainted with the Laws, that govern the Syſtem of the World, he will be able to make a better uſe of his Obſervations, and to compute the Motions of the heavenly Bodies more exactly, than if he had nothing but Obſervations to direct him.

It was my Deſign in theſe two Books, to give my Reader a general Notion of the chief Things diſcover'd by Sir Iſaac Newton *in Natural Philoſophy, and thereby to encourage him to the Study of the more abſtruſe, and at the ſame Time more ſublime Parts of Mathematics, after he has learned the firſt principles of Geometry to fit him for the reading of theſe plain Elements. He will, as it were, go to the Fountain Head, when he reads the Writings of our great Philoſopher, which will reveal ſuch things to him, as were unknown to the profoundeſt Philoſophers before him; and which, tho' publiſhed, are ſtill a ſecret to all but thorough Mathematicians.*

I have only a few Words more to ſay to the Engliſh Reader, concerning the two Engliſh Tranſlations of this Work.

As tedious and diſtaſteful as an Author's complaints generally prove, they cannot, however, be diſallow'd, when they are grounded upon ſuch an Injury done to the Author, as it is his Readers intereſt to be inform'd of.

Soon after the publication of the firſt Volume of theſe Elements, it was tranſlated into Engliſh, *and printed in* London, *with the Name of a Celebrated Profeſſor of Mathematics, eminent for his Writings, inſcrib'd on the Title Page, as if he had look'd over and corrected this Tranſlation. But whoever examines any one Page in the Book, will immediately diſcover the wrong done to that Learned Gentleman, and the abuſe made of his Name; ſince he will every where perceive manifeſt Signs of the Tranſlator's ignorance of the very Principles of Phyſics and Mathematics; not to mention his negligence with regard to* *the correcting of the Additions at the end of the Book, to the Numbers in the Margin, and the diſtinction of the Propoſitions.*

Doctor Deſaguliers, *whoſe knowledge of Philoſophy, and skill in making Experiments are ſo well known, began to tranſlate the ſame Work about the ſame Time as the other, or rather before. But this obliging him to make more than ordinary haſte, he could not himſelf wholly avoid the uſual conſequences of too much precipitation,* &c.

The Tranſlator to the Reader.

THE Reſt of the Author's Preface, I have left out, as is related only to the Diſpute among the Bookſellers. As to the faults in the firſt Volume, (the half of which was done into *Engliſh* and printed in leſs than a Fortnight.) I have carefully corrected them; and given a full Errata in reſpect to the Body of the Book, the Marginal Numbers, and the Plates; a great many of the Alterations and Emendations having been communicated to me by the Learned Author himſelf, and ſome were printed at the End of his Second Volume, as an Additional Errata to the Firſt. I hope the Reader will find very few Faults in this Tranſlation, except what are Faults of the Preſs, moſt of which, I believe, may be corrected by help of the following.

E R R A T A.

PAGE 3. line *penult.* read ſometimes, l. 22. r. Linnen. p. 4. l. 6. r. holds towards. l. 13. inſert [*Plate* I. *Fig* 2.] p. 5. l. 32. r. Wire *a b d.* p. 16. l. 17. r. for we obſerve that. p. 18. l. 13 r. *Dilatation.* p. 23. l. 14. r. by a few. p. 26. l. 29. inſert [*Plate* IV. *Fig.* 1.] p. 39. l. 7. r. as was to be confirm'd by this Experiment. p. 41. l. 9. r. R C. p. 45. l. 8. r. made up of innumerable parallel Rays. p. 48. l. 15, 16, and 17 *muſt all be in Italic Characters.* p. 49. l. 20. r. along *n* G. l. 23. r. between B O and A *n.* l. 24. for F. r. *f.* p. 51. l. 30. for *f* r. *f.* l 34. r. imaginary Focus. p 64. l. 25. *from the Word* when *to the Word* unchangeable l. 29. *Suppoſe thoſe four Lines written in Italic Characters.* p. 66. l. 3. for alter r. alters. p. 69. l. 29. r. leſs diverging. p. 77. l. 17. r. too ſenſible. p. 10. l. 9. *dele.* in p. 81. l 5. r. *poliſh'd Surface.* l. 7. r. *in all its Points reflects the Light only one way.* l 8. r. in Curve as well l. 30. r. [*Fig.* 1.] p. 90. l 10. r. but ſuppoſing A. p. 98. l. 7 r. will be double. p. 99. l. 15. r. Side of the. p. 101. l. 11. r. oppoſite to. p. 1 8. l 5. r. ting'd with Colours. p. 110. l. 18 r. the others between F M. p 113. l. 9 r. the Board Q. p. 118 l. 17. r. Experiment. p. 123. l. 7. r. become wholly reflected p. 124. l. 27. r. but theſe Rays. p. 125. l. 21. r. in the Priſms DD, DD. l. 28. r. the Surface of the Priſm DD, l. 34. r. in the Priſm B B. p. 126. l. 31. r. *is not neceſſary.* p. 128. l. 5. r. is refracted. l. 12. r. is in Part reflected. p. 129. l. 8. r. the incident ones. l. *penult.* r. which is found. p. 137. l. 6 dele they. p. 140. l. 7. r. whoſe Thickneſſes. l. 13. r. whoſe Thickneſſes. p. 141. l. 9. r. as plainly appears. p. 151. l. 31. r the middle Point C. l. *ult.* r. falls in with the Center. p. 154. l. 15. r. in this Reſpect Aſtronomers have been able to make no Obſervations. l. 30. r. Dimenſions of the Orbits. l. 32. r. Nodes of each Orbit. p. 155. l. 4. r. the Mean Diſtance. l. 7. r. the other Diſtances. p. 170. l. 28. r. D, E, F, V. p. 173. l. 30. r. not always viſible. p. 174. l. 7. r. the Emerſion. l. 24. r. there appears p. 180 l 9. r. the Shadow G H. p. 182. l. 1. r. which is intercepted. p. 193. l. 3. r. Meridian of a Place p. 198. l. ult. r. *the moſt intenſe Cold is not upon the ſhorteſt Day.* p. 199. l. 25. r. particular Places. p. 209. l. 20. r. Quantities of Motion. p. 228. l. 11. r. compute the Motion of the Moon. p. 234. l. 2. r. Elliptic Lines. p. 236. l. 15. r. neareſt to it. p. 239. l. 29. r. alſo the Motion. p. 241. l. 21. r. which will follow that Direction only. p. 244. l. 16, 17. r. *and the Augmentation or Addition is to the Gravity.* p. 245. l. 19. r. is to the Gravity. l. 27. is to the Gravity of the Moon, p. 247. l. 33. r. it wou'd be diminiſh'd. p 256 l. 10. r. *Apſides in the Quadratures.* p. 257. l. 32. r. are alſo deduc'd. l 33. r. the Sun upon the Moon. p. 268. l. 15. *dele* is greater, p. 269. l. 7. r. Sides A C. p. 274. l. 27. r. [*Fig.* 1.]

ERRA-

ERRATA in the Marginal Numbers.

PAGE 2. line 12 read (549). l 18. r. (550). page 3. l. 20. r. (553). p. 7. l. 9. r. (562). p. 8. l. 27. r. (* 437). p. 14. l. 33. r. (584). p. 15. l. 21. r. (585). l. 23. r. (586.) l. 26. r. (587). p. 17. l. 1. r. (592). p. 18. l. 14. r. (596). p. 19. l. 5. r. (597). l. 19. r. (598). l. 21. *dele* (598). l. 34. *dele* (600). *and place it before* l. 35. p. 29. l. 18. r. (628). l. 24 r. (629). p. 31. l. 10. r. (631). p. 37. l. 31. r. (641). p. 43. l. 17. r. (659). p. 51. l. 1. r. (682). l. 16. r. (686). l. 22. r. (687). p. 64. l. 21. r. (*753) referring to the Word (*Mention**). l. 25. r. (622). p. 28. r. (623). p. 66. l. 8. r. (729). p. 73. l. 23. r. (759). p. 77. l. 19. r. (772). p. 81. l. 6. r. (779). p. 82. l. 20. r. (786). p. 88. l. 24. r. (802). l. 29. r. 803. p. 92. l. 25. r. (* 816.) p. 94. l. *antepenult*. r. (824). p. 112. l. 14. r. (853). p. 117. l. 1. r. (861). p. 134. l. 4. r. (884). p. 161 l. 1. r. (984). p. 165. l 8. r. (997) p. 185. l. 11. r. (* 966) p. 188. l. 13. r. (*629). referring to the Word (*Refraction**) p. 193. l. 12. inſert an Asteriſm at the Word *Ecliptic** p. 194. l. 4. r. (* 1143) referring to the Word (*ſaid**) p. 203. l. 11. r. (1194). l. 21. r. (1195) p. 231. l. 10. r. (1255). p. 238. l. 27. r. (* 1280). p. 244 l. 18. r. (1288). p. 261. r. (* 1314.) p. 262. l. 4. r. (*1336). p. 270. l. ult. r. (* 1027). p. 279. l. 17. r. (* 1410). p. 280. l. 14. r. (*1417.)

THE
CONTENTS
OF THE
Second VOLUME.

BOOK III.
PART I. Concerning FIRE.

CHAP. I. *OF the Properties of Fire in general,* Page 1.

CHAP. II. *That Fire adheres to Bodies, and is contain'd in them; where we ſhall alſo ſpeak of Electricity,* p. 2.

CHAP. III. *Concerning the Motion of Fire, where we ſhall ſpeak of Heat and Light,* p 13.

CHAP. IV. *Of the Dilatation occaſion'd by Heat,* p. 18.

BOOK III.
PART II. Concerning the Inflexion, Refraction and Reflexion of Light.

CHAP. V. *Concerning the Inflexion of the Rays of Light.* p. 26.

CHAP. VI. *Concerning the Refraction of Light and its Laws,* p. 26.
CHAP. VII. *Of the Refraction of Light, when Mediums are ſeparated by a plane Surface,* p. 39.
CHAP. VIII. *Concerning the Refraction of Light, when a ſpherical Surface ſeparates the Mediums,* p. 44.
CHAP. IX. *Concerning the Motion of Light thro' a more denſe Medium. Where we ſhall take Notice of the Properties of Lenſes,* p. 53.
CHAP. X. *Of Viſion; where we ſhall ſpeak of the Make of the Eye,* p. 58.
CHAP. XI. *Of Viſion thro' Glaſſes, and how to correct ſome Defects of the Eyes,* p. 67.
CHAP. XII. *Of Microſcopes and Teleſcopes,* p. 73.
CHAP. XIII. *Of the Reflection of Light,* p. 80.
CHAP. XIV. *Of Plane Mirrors,* p. 87.
CHAP. XV. *Of Spherical Mirrors,* p. 88.
CHAP. XVI. *Of the Magic Lantern.* p. 98.

BOOK III.

PART III. Of Opacity and Colours.

CHAP. XVII. *Of the Opacity of Bodies,* p. 104.
CHAP. XVIII. *Concerning the different Refrangibility of the Sun's Rays,* p. 108.
CHAP. XIX. *Concerning the Colours of the Rays, and their Unchangeableneſs,* p. 116.
CHAP. XX. *Of the Mixture of Colours, where we ſhall ſpeak of Whiteneſs,* p. 123.
CHAP. XXI. *Of the Rainbow.* p. 127.
CHAP. XXII. *Of the Colours of thin Plates,* p. 136.
CHAP. XXIII. *Concerning the Colours of Natural Bodies,* p. 142.

BOOK IV.

PAKT I. Of the Syſtem of the World.

CHAP. I. *A general Idea of the Planetary Syſtem,* p. 149.
CHAP. II. *Concerning the apparent Motion,* p. 160.
CHAP. III. *Of the Phænomena or Appearances of the Sun from the Motion of the Earth in its Orbit,* p. 164.
CHAP. IV. *Of the Phænomena of the Inferior Planets, ariſing from the Earth's, and their own Motions in their Orbits,* p. 167.
CHAP. V. *Concerning the Phænomena of the Superior Planets, ariſing from their Motions and the Motion of the Earth in their reſpective Orbits,* p. 171.
CHAP. VI. *Concerning the Phænomena of the Satellites, from their Motion in their Orbits. Where we ſhall ſpeak of the Eclipſes of the Sun and Moon,* p. 173.
CHAP. VII. *Of the Phænomena ariſing from the Motion of the Sun, the Planets, and the Moon, about their Axes,* p. 180.
CHAP. VIII. *Of the Phænomena which relate to the Surface of the Earth, and its particular Parts,* p. 185.
CHAP. IX. *Concerning the Phænomena ariſing from the Motion of the Axis of the Earth,* p. 200.
CHAP. X. *Concerning the fix'd Stars,* p. 201.

BOOK IV.

PART II. The Phyſical Cauſes of the Celeſtial Motions.

CHAP. XI. *Concerning univerſal Gravity,* p. 206.

CHAP. XII. *Of the Cæleſtial Matter; where a* Vacuum *is prov'd,* p. 216.
CHAP. XIII. *Concerning the Motion of the Earth,* p. 221.
CHAP. XIV. *Concerning the Denſity of the Planets,* p. 227.
CHAP. XV. *The Phyſical Explanation of the whole Planetary Syſtem,* p. 233.
CHAP. XVI. *The Phyſical Explication of the Moon's Motion,* p. 241.
CHAP. XVII. *Concerning the Figures of the Planets,* p. 263.
CHAP. XVIII. *The Phyſical Explanation of the Motion of the Axis of the Earth,* p. 270.
CHAP. XIX. *Concerning the Tides,* p. 272.
CHAP. XX. *Of the Moon's Denſity and Figure,* p. 281.

Mathematical ELEMENTS OF *Natural Philoſophy,* Confirm'd by EXPERIMENTS.

VOL. II.

BOOK III.

PART I. *Concerning FIRE.*

CHAP. I.

Of the Properties of Fire in general.

THO' we know ſeveral Properties of Fire, yet we are ignorant of a great many things relating to it.

I ſhall not invent Hypotheſes, but reaſon from Experiments, and leave untouch'd what is not fully known.

Fire eaſily penetrates thro' all Bodies, however denſe 544
and hard they are. For we have never yet known any Body, that by the Application of Fire has

not been heated in all its Points; that is, in every Part.

545 *Fire moves very ſwiftly*, as appears from Aſtronomical Obſervations.

546 *Fire unites itſelf to Bodies*; for when they are brought to the Fire, they grow hot, as we ſaid
547 before; *and in that caſe they expand or ſwell:* Which Expanſion is alſo obſerv'd in ſuch Bodies whoſe
548 Parts do not cohere, in which caſe *they alſo acquire a great Degree of Elaſticity*, as is obſerv'd in Air and Vapours.

That *Fire is attracted by Bodies at a certain Diſtance from them*, will be ſhewn in the following
* 611 Part of this Book.*

If any Bodies are violently moved againſt one another, they will grow hot by ſuch a Friction, and that to a great Degree; which ſhews that *all Bodies contain Fire in them*: for by rubbing, Fire may be put in Motion, and ſeparated from a Body, but can by no means be generated that way.

Having laid down theſe general Heads, we muſt examine ſeveral Things more particularly.

CHAP. II.

That Fire adheres to Bodies, and is contain'd in them; where we ſhall alſo ſpeak of Electricity.

AS we have already ſaid, one may prove that Fire is contain'd in all Bodies, becauſe there are no Bodies but what may be heat-
* 550 ed by Attrition;* and that it coheres firmly with the Parts of Bodies, appears in Smoke and Vapours: for Smoke and Vapours are made up of Parts ſeparated from Bodies, and agitated (ſometimes

times very violently) by the Fire that is join'd with them.

There are beſides, ſeveral remarkable Phænomena ariſing from Fire contain'd in Bodies, ſome of which we ſhall here mention; amongſt which there are ſuch as relate very much to Electricity, for which reaſon we muſt alſo treat of the Phænomena of Electricity.

DEFINITION.

Electricity *is that Property of Bodies, by which (when they are heated by Attrition) they attract, and repel lighter Bodies at a ſenſible Diſtance.* 551

Experiment 1.] Take two Pieces of Rock Chryſtal and rub them together, and immediately they will appear luminous all over, tho' they do not acquire any ſenſible Heat by that Attrition. Light (as well as Heat) is a Proof that there is Fire in a Body. The greateſt Light is in thoſe Points where the Bodies touch one another. 552

Experiment 2.] Take a Glaſs Tube 15 or 18 Inches long, and one Inch in Diameter, and rub it with a Linen or Woolen Cloth, and it will emit Light in the Dark. 553

Experiment 3. *Plate* I. *Fig.* 1.] This Tube heated by rubbing, has a very ſenſible Electricity; for if light Bodies, ſuch as Pieces of Leaf Gold, and Soot, be laid upon a Plane, and the Tube be brought near them, they will be put in Motion, attracted, repelled, and driven ſeveral Ways by the Tube. The Tube acts at different Diſtances, according to the different State of the Air; ſometime at the Diſtance of one Foot; when the Air is full of Vapours the Effect is diminiſhed. 554

555 There is one thing remarkable, and very hard to explain in this Experiment, concerning the Direction of the Attrition; when you rub the Tube, one End of it is held in one Hand, whilſt it is rubb'd with the other; which if it be done from the Hand that holds towards the other End of the Tube, the Effect will not be ſenſible; but if you rub from the free End of the Tube towards the End held in the Hand, the contrary will happen. And this happens indifferently, whether you hold the open or the ſhut End of the Tube in your Hand.

556 In the following Experiments, Glaſs Globes are ſwiftly whirl'd about; to perform which, there muſt be a cylindric Neck at each End of every Globe; but only one of theſe Necks is to be open, and both are to have Braſs Ferrels, ſuch as are repreſented at G: a Cock E muſt be ſcrew'd on to the Ferrel at the open Neck, and the oppoſite Braſs Ferrel muſt have a little Wheel *r* of about an Inch and a half Diameter, join'd to it, with a ſmall Braſs Axis ſtanding out: there is juſt ſuch another Piece of Braſs ſcrew'd on to the Cock, ſo that it may be taken on and off at pleaſure. Theſe Axes go about a quarter of an Inch into the Pillars S S, that ſupport the Globe, and are Centers for it to whirl upon when it turns about its Axis.

The Pillars S S, ſtand upon a ſtrong horizontal Board of about an Inch and a half thick, framed into three other Boards, as may be ſeen in the Figure: In that which ſtands foreright, there is an Hole *f* that you may come at the lower part of the Pillar, to make it faſt with a Nut or Screw. The other Pillar S is likewiſe faſten'd by a Screw applied under the horizontal Board, and moved forwards and backwards in a Slit of 4 or 5 Inches long before it be made faſt, in order to take the

Glaſs Globes in and out, and to take in ſuch as are larger or ſmaller than others, according to the different Experiments to be made.

There is a great Wheel R which is turn'd round by means of the Handle M, and thereby gives a very ſwift whirling Motion to the Globe G.

In the Side of the upper Board there is a Slit, along which the Pulley *t* may be moved, by means of the Screw *c*, in order to keep ſtretch'd the Rope that goes round the Wheels R and *r*.

Experiment 4 & 5. *Plate* II. *Fig.* 1.] Apply a Glaſs Globe of about 8 or 9 Inches Diameter, to the Machine abovemention'd, and let it be briskly whirl'd in a dark Place, the Hand all the while being held againſt it, to give it Attrition. 557

If the Globe be exhauſted of its Air, it will appear all luminous within, but moſtly ſo where the Hand touches the Glaſs.

But if the Globe has Air in it, and being whirl'd in the ſame manner, the Hand be applied to it, no Light appears either in the inner or outer Surface of the Glaſs; but Bodies at a ſmall Diſtance from the Glaſs (as for Example, at a quarter of an Inch, or nearer) become luminous; and ſo only thoſe Parts of the Hand held againſt the Glaſs, which terminate, or rather environ the Parts that immediately touch the Globe, are luminous. 558

Experiment 6. *Plate* I. *Fig.* 2.] Take the Globe made uſe of in the foregoing Experiments, and put it in between the Pillars, to whirl it as before: Then take a Braſs Wire *a b c* circularly bent in the upper Part, and fix it ſo that its curve Part may be about 4 Inches off of the Globe, with ſmall Threads hanging from it, which being extended towards the Center of the Globe, 559 come within a quarter of an Inch of the Surface of the Globe.

Whirl the Globe and apply the Hand, and immediately the Threads will be moved irregularly by the Agitation of the Air; but when the Glaſs is heated by the Attrition, all the Threads are directed towards the Center of the Globe, as may be ſeen in the Figure: And if the Hand be applied a little on one Side, or nearer the Pole of the Globe, the Threads will be directed towards that Point of the Axis which is under the Hand.

560 If the Air be drawn out of the Globe, this whole Effect ceaſes.

561 *Experiment* 7. *Plate* I. *Fig.* 3.] Take another Globe like the former; only differing in this, that the open'd Neck muſt have a larger Opening than that of the Globe G, ſo that you may put into it a round flat Piece of Wood *o*, that has a Braſs Wire for its Axis. In order to fix this Piece of Wood in the middle of the Globe, its Axis muſt be firmly ſcrew'd to the middle of the Cover that is join'd to the open Neck of the Globe at *h*: and the Cock E is alſo join'd to the middle of the Cover on the Outſide.

To the wooden Circle ſmall Threads are faſten'd, which being extended, almoſt touch the inner Surface of the Globe.

Turn the great Wheel ſo as to whirl the Globe, and rub it till it becomes warm, as was done in the former Experiments; if you ceaſe to whirl the Globe, and the Hand be taken off, the Threads will immediately ſtretch themſelves out like Radii from the Center towards the Surface of the Globe, yet they hardly remain one Moment at reſt; for tho' the Globe be exactly ſhut, theſe Threads will be put in Motion, as appears by blowing againſt the Globe, tho' you ſtand two Foot off or farther from the Globe. If you bring your Finger towards the Globe, tho' you do not touch it, the Threads next to it will be attracted by the Finger, and directed towards it; nay, and ſometimes they fly from it. If you apply the whole Hand to the Globe, the Threads will be moved violently and irregularly.

And if all the Air be drawn out, as in the foregoing Experiment, the whole Effect ceaſes; and the Threads (both before and after the Friction) only hang down by their Gravity.

If we attend to all the foregoing Experiments, the following Concluſions ſeem to be naturally deduced from them, which we do not give out as certain, but very probable; for we muſt always diſtinguiſh Certainty from Probability.

That Glaſs contains in it, and has about its Surface, a certain Atmoſphere, which is excited by Friction, and put into a vibratory Motion*; for it attracts and repels light Bodies;* the ſmalleſt Parts of the Glaſs are agitated by the Attrition, and by reaſon of their Elaſticity, their Motion is vibratory, which is communicated to the Atmoſphere abovemention'd; and therefore that Atmoſphere exerts its Action the farther, the greater Agitation the Parts of the Glaſs receive when a greater Attrition is given to the Glaſs. 563

* 554, 559, 561.

* 554

The Fire contain'd in the Glaſs is expell'd by the Action of this Atmoſphere; at leaſt it is mov'd with it. For when light Bodies are put in Motion at a Diſtance from the Glaſs, the Bodies alſo become lucid at a Diſtance.* 564

* 559, 558.

It is plain, that *this Atmoſphere and Fire is more eaſily mov'd in a Place void of Air*: For if the Globe be exhauſted of its Air, there can be perceiv'd no Light, nor any Effect of Electricity on the outſide of the Globe *, but the inſide of the 565

* 557, 560

Globe appears very luminous, and this Fire is perceiv'd to be in greater Quantity in this Experiment than in that immediately after mention'd *. * 558

But the Action of the Electricity does alſo * 562 ceaſe on the inſide when the Air is drawn out *; which ſeems to overthrow what we ſaid of the more eaſy Motion of the Atmoſphere of Glaſs *in Vacuo*: But yet it is not probable that it ſhou'd move no whither in this Caſe. On the contrary it ſeems to go the ſame way as the Fire, and to move that way where there is the leaſt Reſiſtance; and that the ceaſing of the Action of Electricity is to be attributed to the want of Air, 566 by means of which *the Threads are moved by the Atmoſphere*; as we ſhall hereafter ſhew *; and the * 605, 607 Fire, which freely penetrates all Bodies, acts upon them violently *by means of the Air* or Vapour.

But laying aſide Conjectures, tho' they have a great many Experiments for their Foundation, let us return to other Things relating to Fire, as ſeveral Experiments are to be made *in Vacuo*, we muſt deſcribe the following *Machine* contriv'd to give Attrition to Bodies *in Vacuo*.

567 *Plate* II. *Fig.* 2.] Let M be the Air-Pump de- * 457 ſcrib'd before *, L L the Braſs Plate of the Pump on which the Glaſs Receivers are ſet; on each ſide of the Plate there is a wooden Pillar, A D, A D, which Pillars ſtand on the Board that carries the Air-Pump Plate having their Baſe upon it, and a part below the Baſe, and going thro' the Board with an Hole in it, to receive two croſs Pieces of Wood or Wedges that make them faſt during the Experiment, but ſo that the ſaid Pillars may be taken away afterwards.

The Glaſs Receiver in which the Experiments are to be made, is about 9 Inches high, and 6 in Diameter, with a Cover * that has annex'd to it a Box or Collar full of oil'd Leathers through which a Braſs Axis paſſes; and leaſt in the whirling round of the Axis the lower end ſhou'd move, part of the Box is made ſquare, ſo as exactly to fit a ſquare Hole in the Horizontal Board E E that preſſes on the Cover, and is made faſt by bringing down the Nuts or Screws B B at each end, without bearing upon the Shoulders of the Pillars.

* 440

Towards the upper Part of the Pillars there is a narrower horizontal Board F F preſs'd down alſo and faſten'd with Nuts, which has fix'd to it on the under ſide a piece of Braſs *g*, with an Hole in it for the upper end of the above-mention'd Axis to turn in, whilſt the biggeſt part of this Axis being in the middle of the Glaſs, has an outſide Screw upon it, with the two Wing-Nuts *d*, *d*, moveable upon it, in order to faſten ſeveral Bodies upon the Axis.

The lower End of the Axis turns in the Hole *c*. The braſs Spring *ff* is join'd to the Piece *c* which ſcrews it down to the Air-Pump Plate at the Hole where the Air is drawn out; but there muſt always be made a ſmall Hole or Paſſage in the Piece *c*, for the Air to be drawn out at.

Having exhauſted the Receiver, the Axis above-mention'd (by reaſon of the oil'd Leathers in the Collar P) may be turn'd round without admitting any Air; but to give it a quick Motion there is a little Braſs Wheel *r* of about 2 Inches Diameter, with Points in its Groove, that the Rope that turns it round may not ſlip.

The great Wheel R, of about 3 Foot Diameter with its Frame, is brought up cloſe to the Air-Pump, and made faſt to its Foot by a Screw.

The Rope that goes about the leſſer Wheel *r*, is brought down over Pullies obliquely placed in the upper part of the Pillars C, C, and being over them, comes down to the great Wheel which it goes round; ſo that by turning the vertical Wheel R, the Braſs Axis above deſcribed, is carried round very ſwiftly, whereby a Motion is communicated to Bodies *in Vacuo* for ſeveral Experiments.

568 *Experiment* 8.] Take a Glaſs Globe of three Inches Diameter, or of two Inches and a half Diameter, with an Hole on each ſide, where it may alſo have cylindric Necks. The Axis above-mention'd muſt go thro' thoſe Holes, in order to give the Globe a whirling Motion; pieces of Cork muſt be put on each ſide of the Globe to cover its Holes, and made faſt with the Nuts *d*, *d*, in the manner that they appear in the Figure, to hold faſt together the Plates or little Wheels thro' which the Axis goes.

This Globe, thus fix'd, will be ſwiftly mov'd *in Vacuo* with its Axis, by turning the Wheel R: To cauſe Attrition, a piece of Woollen Cloth muſt be tied on to each ſide of the Braſs Spring *f*, *f*, which by its Elaſticity preſſes the Globe hard on each ſide.

Making the Experiment in the dark, the Globe will appear luminous; and if the Motion be continued till the Globe grows hot by the Attrition, the Light will indeed be increaſed, but will appear fix'd in the Places where the Attrition is made.

569 It follows from that Experiment, that *the Fire contain'd in Glaſs does not want Air to make it viſible*, for it grows hot, and ſhines when both the internal and external Air are taken out.

570 *Experiment* 9.] Take a round Piece of Wood of 2, or 2 ½ Inches Diameter, and about ½ an

Inch thick, and let it have ſeveral Hollows cut in its Edge, that it may be encompaſs'd round with Beads of Plaiſter, which may be made faſt to it with Threads going thro' them. Let this piece of Wood thus prepar'd be made faſt upon the Axis above-mention'd, in the ſame manner as the little Globe had been faſten'd; then give Attrition *in Vacuo*, as in that Experiment, and Light will be thereby produced in the dark.

Experiment 10.] That Quickſilver contains Fire is plain, from Experiments made upon it, *in Vacuo*. For if Mercury well clean'd be ſhak'd about in an exhauſted Glaſs, it will appear luminous. 571

If you put Mercury into a Glaſs Globe, the Globe may be whirl'd round, as in the former Experiments, which will be delightful to ſee, if the Glaſs be mov'd ſlowly. If Mercury has no Tin mix'd with it, it may be clean'd with boiling-hot Vinegar. 572

The Globe that has the Mercury in it may be exhauſted by ſcrewing on to it a Pipe about 2 Foot long, the lower end of which muſt be ſcrew'd on to the Hole in the middle of the Plate of the Air-Pump. 573

Then if you cover both that Hole and the Hole thro' which the Air is drawn out with one of the Receivers above-mention'd, the Air will be eaſily drawn out of the Globe.

Plate I. *Fig.* 4.] Take a Plate O, and having ſcrew'd on to it the Pipe E E, whoſe other end is ſcrew'd to the Air-Pump, put the Glaſs Receiver R upon it, and pump out the Air from it. The Pipe thro' which the Air is drawn out muſt ſtand up beyond the Plate in the Receiver about 4 or 5 Inches, be bent, and have a ſmall Hole in it; which muſt be taken 574 ken care of, for fear any Mercury ſhou'd get into the Air-Pump.

The middle of this Plate has a braſs Pipe B; whoſe lower end that is without an Hole comes down almoſt to the bottom of the Veſſel V, that contains very clean Mercury: There is an Hole in the ſide of the Pipe exactly ſhut by the Pin A. The upper end of this Pipe has a very ſmall Hole in it, and comes up thro' the Plate into the Receiver.

The Height of the Receiver R is about 16 Inches, and its Diameter 4 Inches; pump the Air out of it, and then open the Hole in the ſide of the Pipe B, and the Mercury by the Preſſure of the external Air will go up the Tube, and will ſpout very ſtrongly into the Receiver, ſtriking againſt the top of it.

The Experiment muſt be made in a dark Place, and the Mercury will appear luminous.

575 *Experiment* 11.] Chymiſts make a certain Preparation of Urine, which they call *Phoſphorus of Urine:* which muſt be kept in Water. If it be roll'd up into ſmall cylindrical Pieces like a Pencil, and you write with it upon a Paper, when you hold the Paper in a dark Place, you will ſee Letters of Fire. The *Phoſphorus* itſelf, when you take it out of the Water, will grow hot and ſmoke; all which ſhews that the *Phoſphorus* contains a great deal of Fire.

576 In this Experiment *we may obſerve that Water acts upon the Fire contain'd in the* Phoſphorus; for *it keeps it in,* ſo that it cannot get out ſo long as the Phoſphorus is cover'd with Water: but as ſoon as the Water is taken away, the Heat and Smoke immediately ſhew that the Fire iſſues

577 out of the Phoſphorus. *The Air* alſo *does in ſome meaſure keep in the Fire contain'd in hot Water;* that

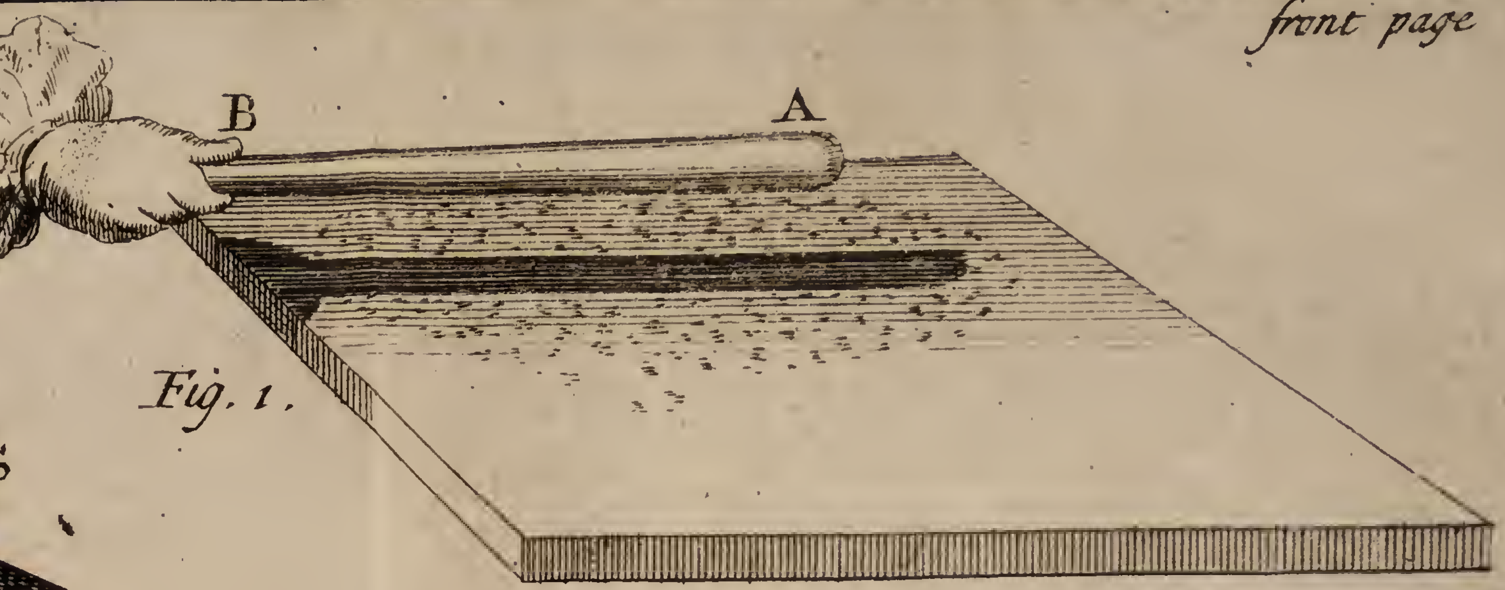


Fig. 1.

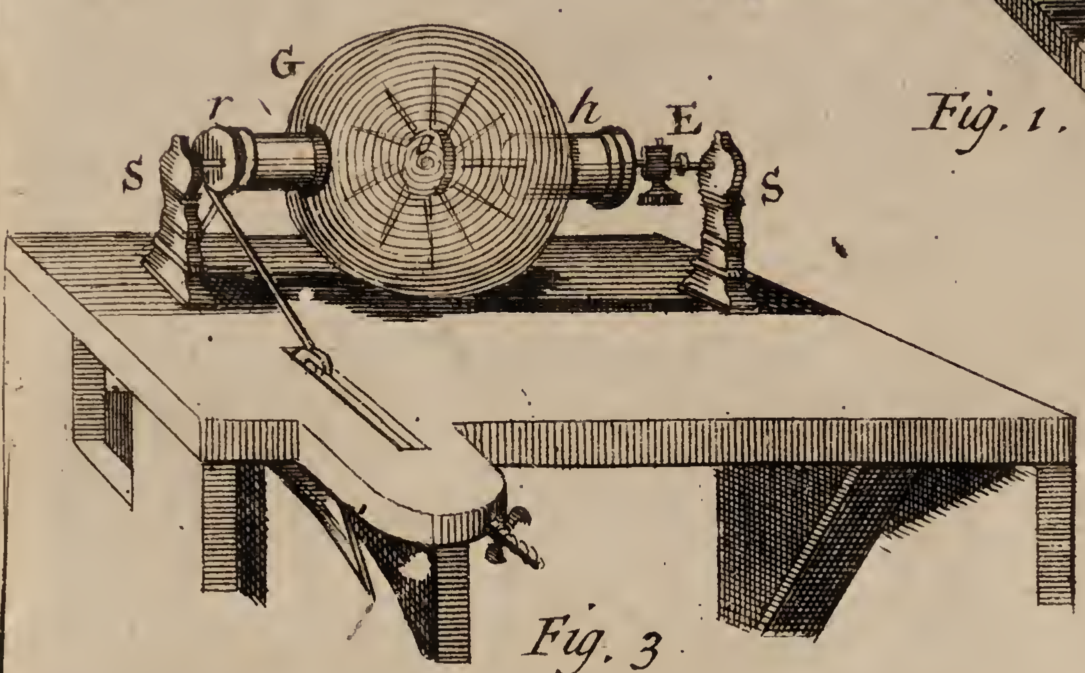


Fig. 3

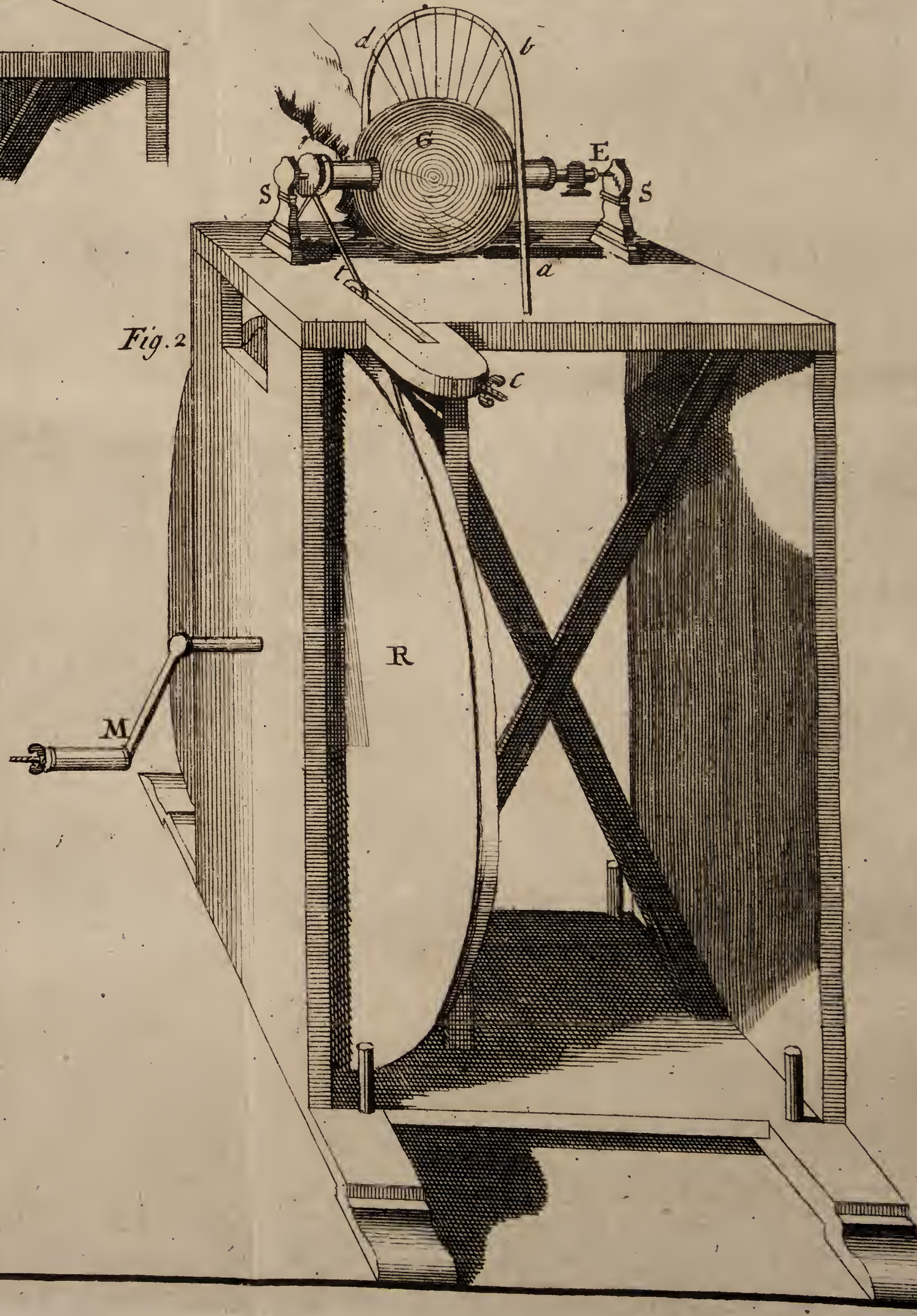

d
b
G
S
E
S
t
a
c
M
R

Fig. 2

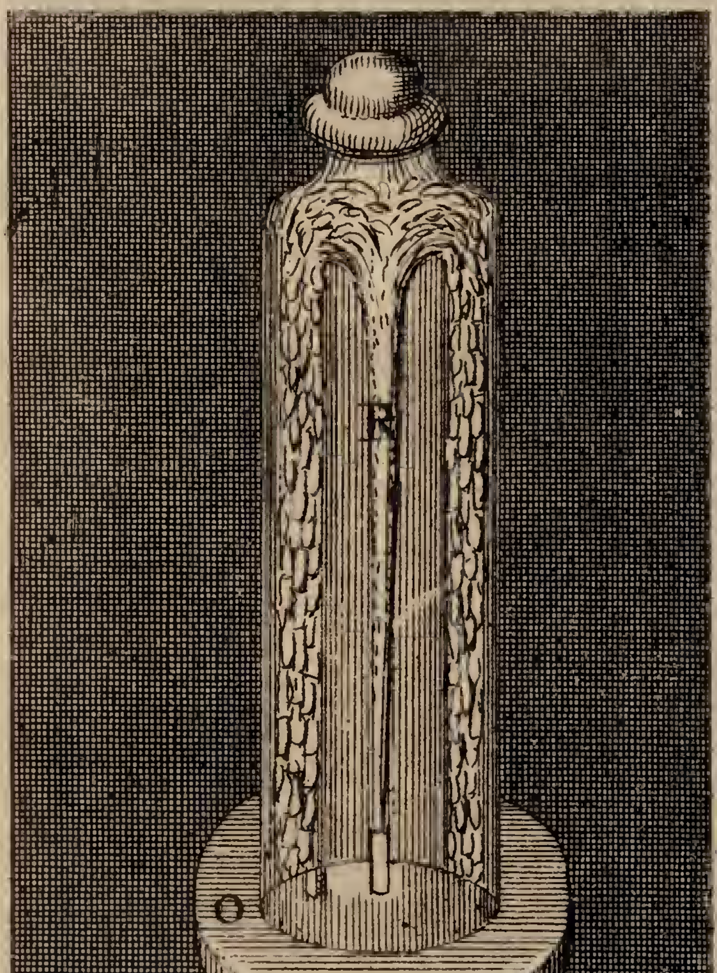


Fig. 4

that is, hinders it from going out of it ſo faſt as it will do *in Vacuo.*

Experiment 12.] Take two Veſſels that are equal and alike, and put an equal quantity of boiling Water into each of them. Let one of them be ſet upon the Air-Pump Plate under a Receiver, and pump out the Air; when you are pumping, the Water boils violently by the Action of the Fire that goes out of it; and then ſoon becomes only lukewarm, whilſt the Water in the other Veſſel which remain'd in the open Air has ſcarce loſt any of its Heat.

578 One may obſerve ſomething like this in ſhining Wood; for ſome Wood that is rotted in the Ground ſhines, when it is taken out; the Earth that encompaſs'd the Wood kept in the Fire, which goes out when that is remov'd, and the Wood continues to ſhine for ſome Days. In an exhauſted Receiver the Light is ſoon deſtroy'd, and is not reſtor'd by the Re-admiſſion of the Air.

But it cannot be eaſily determin'd how Fire is confin'd in a Body by the ambient Bodies, nor is it eaſy to find out what Action produces this Effect; it is hardly probable that Preſſure is here much concern'd, ſince Fire does eaſily penetrate all Bodies by its Subtility.

CHAP. III.

Concerning the Motion of Fire, where we ſhall ſpeak of Heat and Light.

WE have ſaid that Fire moves very ſwiftly *, and this Motion in different Circumſtances produces different Effects. Heat and Light

* 545

Light are to be attributed to the different Mo-
579 tions of Fire. *Heat in a hot Body is the Agitation
of the Parts of the Body and the Fire contain'd in it,*
by which Agitation a Motion is produc'd in our
Bodies, which excites the Idea of Heat in our
580 Mind. *Heat in reſpect of us is nothing but that Idea,
and in the hot Body is nothing but Motion.* Here
we muſt call to mind what has been ſaid of the
Senſations in general (N. 502) which alſo may
be referr'd to Light.

581 *When Fire enters our Eyes in Right Lines, by
the Motion that it communicates to the* Fibres *in the
bottom of the Eye, it excites the Idea of Light*; of
which Motion of the Fibres we ſhall ſpeak more
* 716 particularly hereafter *. *A rectilinear Motion* is
582 the Motion of Light, as it appears from its be-
ing eaſily ſtopp'd by an Obſtacle. On the con-
trary, ſuch a Motion *is not requir'd in Heat*; and
that *an irregular Motion is more proper for it*, may
be prov'd, becauſe the Rays that come directly
from the Sun to the Top of a Mountain,
produce no ſenſible Heat; whilſt in the Valley,
where the Rays are agitated with an irregular
Motion by ſeveral Reflexions, there is often produc'd
a very intenſe Heat.

DEFINITION.

A Body *is ſaid to be* lucid, *when it emits Light*, that is, when it gives Fire a Motion in right Lines.

583 That *there is not always Light where there is Fire*, is beyond all doubt; for we daily ſee hot Bodies that do not ſhine.

But *whether there be any lucid Body without Heat, cannot be determin'd.* Heat in all Bodies is a Motion that may be infinitely diminiſh'd; and there may be ſuch a Motion, tho' it be not ſenſible to us, becauſe often we cannot diſcover any thing of Heat; for certainly there are a great many lucid Bodies in which we can perceive no ſenſible Heat.* Concerning which it *571 may be obſerv'd, that no Heat is ſenſible to us, unleſs the Body that acts upon our Organs of Senſe has a greater Degree of Heat than that of our Organs. Which ſhews us that the Judgment of our Senſes concerning Heat is wholly uncertain.

When the ſmalleſt parts of which any Body is made up are agitated, either by Attrition, or the Action of Fire applied externally to it, or any other way; the Fire is ſeparated from the ſmall Particles and agitated in the Body; then alſo the Fire and the Particles of the Body act upon one another by their Attraction, as is prov'd by the Experiments which we ſhall hereafter mention.* By this Action ſome Parts are *611 ſeparated from the Body, and carried off from it by the Motion of the Fire. And this is the cauſe why *hard Bodies are often ſet on Fire by a* 586 *violent Attrition.*

Hence we deduce, that *the burning of Bodies is a Separation of their Parts by the mutual Action of the Fire, and thoſe Parts on each other*; ſome of *thoſe Parts, carried off by the Motion of the Fire, make* 587 *Flame and Smoke.*

We ſee beſides, that a Body that is burn'd by the Application of Fire, is not only diſſolv'd by the Action of the external Fire, but alſo by the Action of the Fire contain'd in the Body itſelf; and that the Heat is encreaſed by the Application of new Fire, and the Augmentation the Agitation of the Fire which the Body itſelf contains; and therefore that *the Heat is not in propor-* 588 *tion to the quantity of Fire.*

As to the Motion of Light, it is plain, as we ſaid *, that it is perform'd in right Lines; but *581 whether it be ſucceſſive or inſtantaneous, is diſputed; that is, whether at the ſame Moment that a Body begins to ſhine, the Light is ſenſible at any Diſtance, or whether the Light goes on ſucceſſively to Places more and more diſtant.

589 It ſeems clearly to follow from ſeveral Aſtronomical Obſervations, that that Motion is ſucceſſive, and Philoſophers did not long doubt of it; but by ſome later Obſervations, the Concluſions drawn from the former, are weaken'd, and we are obliged to confeſs that the Motion of Light has ſomething unknown to us.

To ſay that a Motion from one Place to another is not ſucceſſive, implies a Contradiction,
590 and *it can ſcarce be doubted that Light moves from one Place to another.*

We obſerve alſo that Fire is carried off in Vapours and Smoke; in which Caſes Fire carries with it the Bodies to which it adheres, and yet is often mov'd very ſwift: If the Subtility of Fire be conſider'd, it will eaſily be found that it is immenſly retarded by the Bodies to which it adheres; and that as ſoon as it is freed from them, it is mov'd with a very great Velocity.

There are ſeveral other Things very well worth obſerving in reſpect to Light and Heat, but a great many of them are hard to explain. In Natural Philoſophy, when we are ignorant of the Cauſes, we muſt only mention the Effects.

591 We ſee *ſeveral heated Bodies* that *become lucid if their Heat be encreas'd*; ſuch are Metals: They emit Fire by the Agitation of their Parts, but if the Motion of the Parts be encreaſed, part of the Fire is mov'd in right Lines, and the Body ſhines.

Thus if Smoke be made hotter by applying Flame to it, it is chang'd into Flame; that is, it becomes a lucid Body.

Experiment 1. *Plate* II. *Fig.* 3.] Having blown out the Candle C, which ſends out the Smoke F; let another lighted Candle A be brought to it, and the Smoke of the firſt will be chang'd into Flame, and that ſucceſſively quite to the Candle C, which is thus lighted by the Candle A, tho' it be 7 or 8 Inches from it.

We have ſaid that Air acts upon Fire *; one of * 577
its Effects upon it, that in many Caſes is not to be overlook'd, ſhews itſelf in reſpect of Light. For *the Preſence of the Air is often neceſſary for the* 593
Production of Light or Preſervation of Fire, which may be obſerv'd in the burning of all thoſe Bodies that go out when the Air is taken away from them.

Experiment 2.] Put a lighted Candle under the Receiver of the Air-Pump; exhauſt the Receiver, and the Candle will immediately go out.

Plate II. *Fig.* 2. *Experiment* 3.] Take a round Plate of Steel of about 3 Inches Diameter, with an Hole in the middle to receive the Axis which is to be mov'd *in Vacuo* *, and let it be preſs'd * 567
and fix'd between two round Pieces of Wood by help of the Screws *d, d*; let Pieces of Flint be faſten'd to the Spring *f, f*, ſo that by the Motion of the Axis the ſteel Plate may rub nimbly againſt the Flints. As long as there is any Air in the Receiver the Attrition will produce Sparks of Fire; but when the Air is drawn out, tho' you continue the Attrition, you can perceive no Light; but upon re-admitting the Air, it becomes again ſenſible.

594 We obſerve alſo on the contrary that *very often the Abſence of Air is neceſſary for Light*, as might be
* 557 obſerv'd in the Experiments already mention'd *.
571 *And* laſtly, That *taking away the Air, the ſame*
595 *Light which may be ſeen in the open Air, is* ſometimes *encreaſed.*

* 575 *Experiment* 4.] With the *Phoſphorus* * abovemention'd write or draw Figures upon Paper, and they will ſhine in the dark, as we ſaid before; but the Paper will become much brighter *in Vacuo.*

CHAP. IV.

Of the Dilation occaſion'd by Heat.

ALL Bodies are dilated by the Action of
* 547 Fire *; but *that Dilatation* changes as the Heat changes; ſo that it *ſeems to depend rather upon the Motion than the Quantity of the Fire*; for Bodies are expanded as well by rubbing as by applying Fire to them externally.

Experiment 1. *Plate* III. *Fig.* 1.] Take a ſquare Iron Bar about 3 Foot long and $\frac{1}{4}$ of an Inch thick, and having laid it upon a Board between two firm Obſtacles or Standards O, O, between one of the Obſtacles and one End of the Bar thruſt in an Iron Ruler about 4 or 5 Inches long, (made Wedge-Faſhion, being $\frac{1}{4}$ of an Inch broader at R than at *r*, and divided into equal Parts) as far as it will go; and obſerve the Diviſion that is againſt the End of the Bar, which muſt be a little oblique, that it may the better apply itſelf to the Ruler.

Then let the Bar be heated, either by Attrition or Fire; then let it again be put between the Standards, and the Ruler thruſt in between: As the Ruler will not go in ſo far as the Diviſion that was obſerv'd before, it is plain that the Bar is lengthen'd by Heat.

Experiment 2. *Plate* II. *Fig.* 4.] That *Liquids as well as Solids are dilated by Heat* may be prov'd in the following manner. Take a Glaſs Ball G 597 that has a ſmall Tube ED for its Neck, and fill it with ſome Liquor up to what Height you pleaſe in the Tube, and the Liquor will aſcend in the Tube when you heat the Ball; a ſmall Degree of Heat will produce this Effect, even tho' you uſe Mercury, the denſeſt of all Fluids. The Experiment will be made in the ſame manner, but better, if inſtead of a Ball you uſe an hollow Cylinder C with the long Tube BA joyn'd to it; for the whole Liquor will be ſooner heated in a Cylinder than in a Ball.

If the Tube ED or BA be divided into equal Parts; or the Tube with its Ball or Cylinder be fitted to a Frame on which equal Diviſions 598 are mark'd, the Heat may in ſome ſort be meaſured by this Machine: For the Liquor riſes or ſubſides in the Tube as the Heat of the neighbouring Bodies is encreas'd or diminiſh'd. Such Inſtruments are call'd *Thermometers*, and are of common Uſe. They do indeed ſhew a Change 599 in the Heat, but it is uncertain whether they ſhew the Degree of Heat; that is, it is not known what Relation there is between the Change of Expanſion and the Change of Heat, ſo as to enable us to compare together the Degrees of Heat, by comparing the Degrees of Dilatation.

600 If the Ball G or Cylinder C be ſuddenly heated, the Liquor in the Tube will immediately deſcend, but immediately after riſe. By reaſon of the ſud-

den Heat the Glaſs itſelf grow hot ſooner than the Liquor contain'd in it; and therefore when the Glaſs is dilated by the Heat, the Cavity grows bigger, ſo that the Liquor deſcends; but the Heat being preſently communicated to it, it riſes again by its Expanſion.

From the Expanſion of Bodies it is evident
601 that *the Particles of which Bodies conſiſt, from the Action of the Fire, acquire a repellent Force, by which they endeavour to fly from each other,* and which acts contrary to that Force by which the Parti-
*31 cles come to each other *. As long as this laſt Force is ſtronger than the other, the Particles cohere more or leſs, according to the different Degree of Heat. When the repellent Force is almoſt equal to the attractive, the Particles which were before firmly join'd, ſcarcely cohere, yield to any Impreſſion, and are eaſily mov'd one amongſt another; whence we ſee that *a So-*
602 *lid Body is chang'd into a Liquid by Heat,* which may be obſerv'd in all Bodies that are liquified by Heat, and return to their firſt State upon the Diminution of the Heat. It is a Queſtion, *Whether all Fluidity is not owing to Heat?* which
603 *cannot be determin'd,* becauſe we know of no Body that is entirely without Fire in it; it is certain that Heat is not only the Cauſe of Fluidity in Metals, Wax, and ſuch like Bodies, but that ſeveral Bodies, which are commonly reckon'd Fluid, are only ſo by reaſon of their Heat; thus
604 *Water is melted Ice*; for when part of the Heat of the Water is gone, it grows fix'd.

605 Heat may be ſo encreas'd, that in ſome Bodies the attracting Force is overcome by the repelling Force; in which Caſe the Particles fly from each other; that is, acquire an elaſtic
*431 Force, ſuch as the Particles of Air have *, which Elaſticity is encreaſed even in the Air by Heat.

Plate 2.

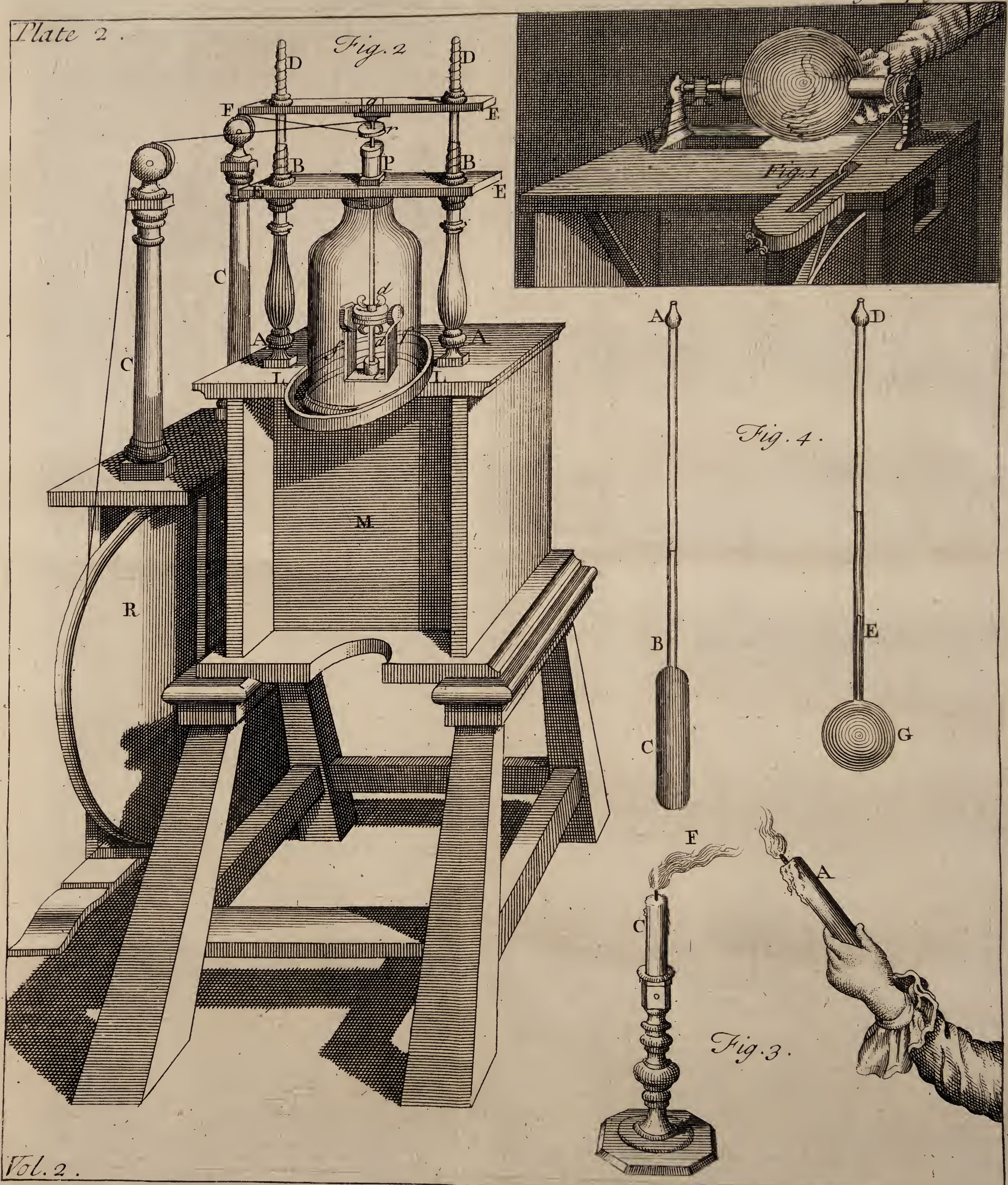


Fig. 2
D
D
F
g
E
r
B
P
B
E
E
C
d
A
A
L
L
C
M
R
Fig. 1
Fig. 4.
A
D
B
C
E
G
F
A
C
Fig. 3.

Vol. 2.

We may obſerve this Effect in Smoke and Vapours.

Experiment 3. *Plate* III. *Fig.* 2.] Take an hollow Braſs Ball E, of about 4 Inches Diameter, with an Handle M; this Ball has a Pipe T with an Hole of hardly the twentieth part of an Inch. Let this Ball be heated, and the Air in it will expand itſelf * and come out thro' the Pipe; * 597
then immerging the Ball in Cold Water, the Air will be again condens'd by the cold, and the Water will go into the Ball by the Preſſure of the Atmoſphere upon its Surface.

If this Ball thus partly fill'd with Water be laid upon the Fire, the Moment that the Water is chang'd into Vapours, thoſe Vapours will go out thro' T; but if the Heat be encreas'd ſo as to make the Water boil violently, the Vapours compreſs'd in the upper part of the Ball, will, by their Elaſticity, endeavour to recede from each other every way, and ruſh violently out of the Pipe. Such an Inſtrument is call'd an *Æolipile.* *606*

Experiment 4.] The following Experiment *607*
ſhews a more ſenſible Effect of the Elaſticity of Vapours.

Plate III. *Fig.* 3.] Take the Ball E which is alſo of 4 Inches Diameter, made of Braſs or Copper, but thicker than the former, and let it be plac'd upon a little light Cart, ſuch as is repreſented in the Figure. In its upper Part it has a ſquare Pipe T. In the middle of this Pipe there is a Separation, and the hind Part of the Pipe communicates with the Ball. There is an Hole of about $\frac{1}{8}$ of an Inch, in the middle of the Separation of the Pipe, which Pipe is open forwards. This Hole is ſhut up with a long Plate that goes through two Holes in the

Sides of the Pipe, and applies itſelf to the abovemention'd Separation. As the Plate is made Wedge-wiſe, if you ſtrike upon it with a Hammer, it will exactly ſhut the Hole.

Take this Ball off of the Cart, and open the Hole, and having heated the Ball, immerge it in Water, to let it be in part fill'd, as in the laſt Experiment. Then having ſhut the Hole, ſet the Ball again upon the Fire till the Water boils violently; and then if you make it faſt to the Cart, and open the Hole, the Vapour will fly out violently one way, and the Cart be car-
608 ried with the Ball the contrary way.

The Vapour being very ſtrongly compreſs'd, endeavours to recede equally every way, and therefore oppoſite Preſſures deſtroy one another; but when the Hole is open'd, the Vapour which goes out does not preſs; therefore the Preſſure one way being taken off, that which acts in a contrary Direction prevails, and the Cart is
609 mov'd along

A Sky-Rocket riſes up into the Air, becauſe the Gun-powder being ſet on Fire, acquires an Elaſticity, and its Parts endeavour to recede every way: As the Pipe or Caſe of it is open at one End, it is leſs preſs'd that way, and conſequently at the other end the Preſſure prevails, and carries up the Rocket.

BOOK III.

PART II.

Concerning the Inflexion, Refraction and Reflexion of Light.

CHAP. V.

Concerning the Inflexion of the Rays of Light.

HAVING premis'd in the foregoing Part what regards Fire in general; let us again farther examine the Properties of Light and the Phænomena ariſing from them.

The Things obſerv'd concerning Light are very wonderful, yet moſt of them are explain'd a few Laws of Nature.

Light moves in right Lines *, can be intercepted by an Obſtacle which wholly ſtops ſo much Light as comes upon it, but ſtops no more. * 581

DEFINITION.

Any Light conſider'd according to the Direction of its Motion, if it be all carried in the ſame Direction, is call'd, a Ray of Light. 610

Such is a Beam of the Sun's Light going thro' an Hole.

Fire, as has been ſaid, is attracted by Bodies *; the notable Effects of which Attraction may be obſerv'd in the burning of Bodies; they are alſo ſenſible in Light; for *when Light paſſes near Bodies, it is turn'd out of the ſtreight way*; which may be diſtinctly perceiv'd by the following Experiment.

* 549

611

Experim. 1. *Plate* III. *Fig.* 4.] Take a little Board T about 6 Inches long and as high, with an Hollow *c c* in its Surface, in which two Plates of Steel ſlide, each of which has an Edge like a Knife: the two Edges may be brought together in the middle of the Board, and be join'd together exactly. At the Place where they meet there is a ſquare Hole in the Board of almoſt an Inch, that a Beam of Light let into a dark Room thro' an Hole of a quarter of an Inch in Diameter, may paſs thro' the ſaid ſquare Hole, ſo as to come to the Plates.

If the Diſtance between the ſaid Edges be of about the 10th part of an Inch, and the Light be made to paſs between them, the Board being ſet at the Diſtance of 3 Foot from the Window, if the Light falls upon the Paper A, at 5 Foot beyond the Board, there will appear on each ſide of the tranſmitted Beam a Light like that of the Tail of a Comet; which proves that the *Light is inflected* as it paſſes by the Edges of the Plates, as is plain from the Figure.

If you bring the Plates nearer, (as for Example) within the hundredth part of an Inch, inſtead of the Light above-mention'd, you will, on each ſide of the Light of the Beam upon the Paper, ſee three colour'd Fringes parallel to the

Edges of the Plates; which will ſtill appear more diſtinct, if the Hole in the Window be made leſs. I ſhall hereafter explain whence theſe Colours ariſe. Now it is enough to deduce from this Experiment, that Light *is attracted* by Bodies that inflect its Rays; for if there was not a Motion towards the Body, the whole Beam would have continu'd in its direct Motion.

But *the Action of Bodies, by which they act upon the Light to attract it, exerts itſelf at a ſenſible Diſtance*; as is plain from the Experiment. 612

Experiment 2. *Plate* III. *Fig.* 4.] Every thing elſe being as in the former Experiment, if the Plates be brought nearer together within $\frac{1}{400}$ part of an Inch, no Light will appear upon the Paper between the Fringes above-mention'd; ſo that in this Caſe all the Light which paſſes between the Edges is inflected on either ſide, ſo as to produce the Fringes above-mention'd. Which plainly ſhews that Steel acts upon Light at leaſt at the Diſtance of $\frac{1}{800}$ part of an Inch.

It is alſo proved, that *That Action is encreas'd as the Diſtance is diminiſh'd.* 613

Experiment 3. *Plate* III. *Fig.* 4.] Things being ſtill in the ſame Diſpoſition, leſſen the Diſtance between the Plates; and the Fringes will vaniſh ſucceſſively, till the Plates being join'd together, no Light paſſes between them. The Fringes which vaniſh firſt are thoſe that are produc'd by the Rays which are leaſt inflected; and thoſe vaniſh laſt which are produc'd by the Rays that are moſt inflected; that is, when the Edges come towards one another, the Shadow between the Fringes made by each Edge is continually encreas'd, till at laſt the whole Light on each ſide vaniſhes. Whence it plainly follows, that the Rays are more inflected the nearer they paſs by the Edges; that is, the Attraction is encreaſed as the Diſtance is diminiſh'd.

614 But this Attraction has ſomething particular, for *the Attraction of one Edge is increaſed, as the other is brought near it.* Which is plainly ſeen in this Experiment; for as the Edges are brought towards one another, the Inflection of the Rays continually becomes greater.

CHAP. VI.

Concerning the Refraction of Light and its Laws.

615 *ALL that gives paſſage to Light, is call'd a* Medium.

Glaſs, Water, and a Vacuum itſelf are Mediums.

When a Ray of Light goes out of one Medium into another, it is often turn'd out of the right Line.

DEFINITION II.

This Inflection is call'd *Refraction.*

616 *In order to produce Refraction, the Mediums muſt be of different Denſities, and the Ray muſt make an oblique Angle with the Surface that ſeparates the Mediums.*

618 *Refraction ariſes from this, that the Rays are more attracted by a denſe then by a rare Medium*; from which Attraction, that we have prov'd in the foregoing Chapter, all that relates to Refraction may be deduc'd.

619 Let E F be the Separation of the Mediums; and let X be in the denſer, and Z in the rarer Medium. All the Particles have an attractive Force *, and this Force alſo obtains in Light. * 31.

*611. Let the Diſtance at * which the Particles exert their Action, be that which is comprehended between the Lines E F, and G H. Therefore the

Plate 3.

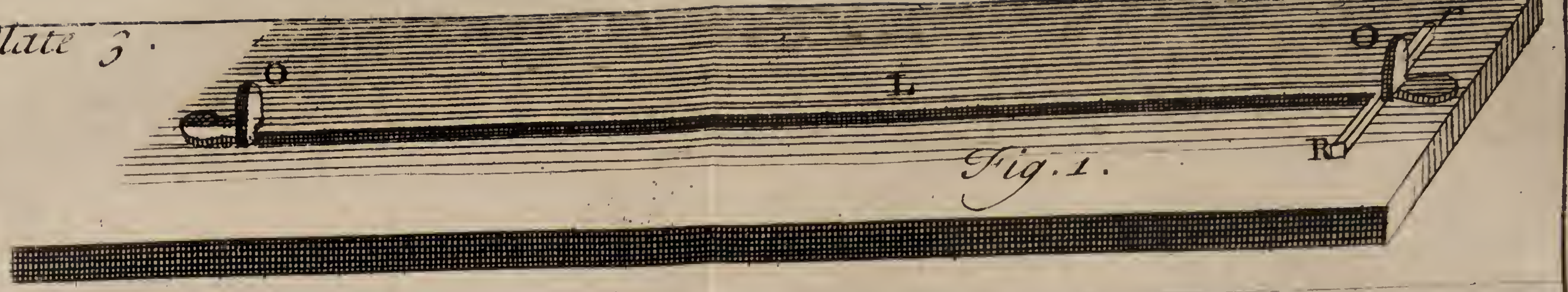


Fig. 1.

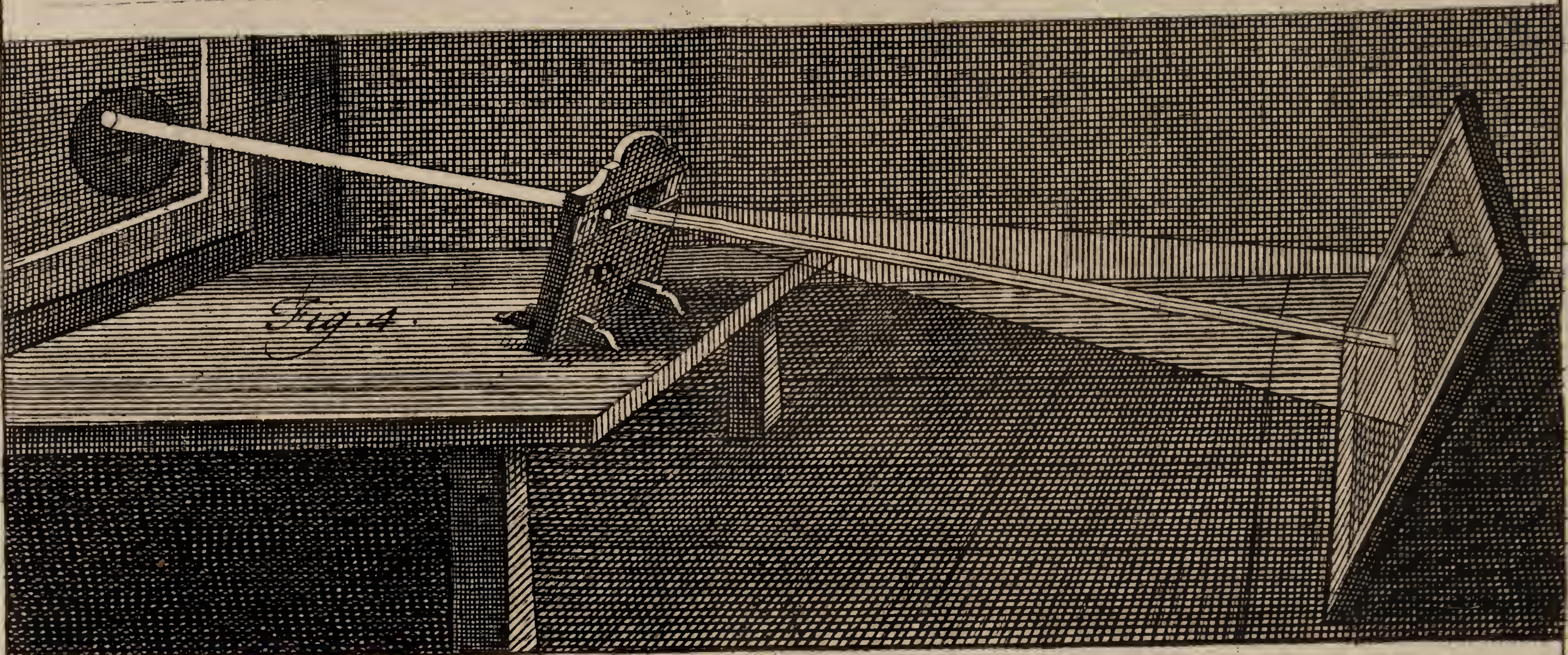


Fig. 4.

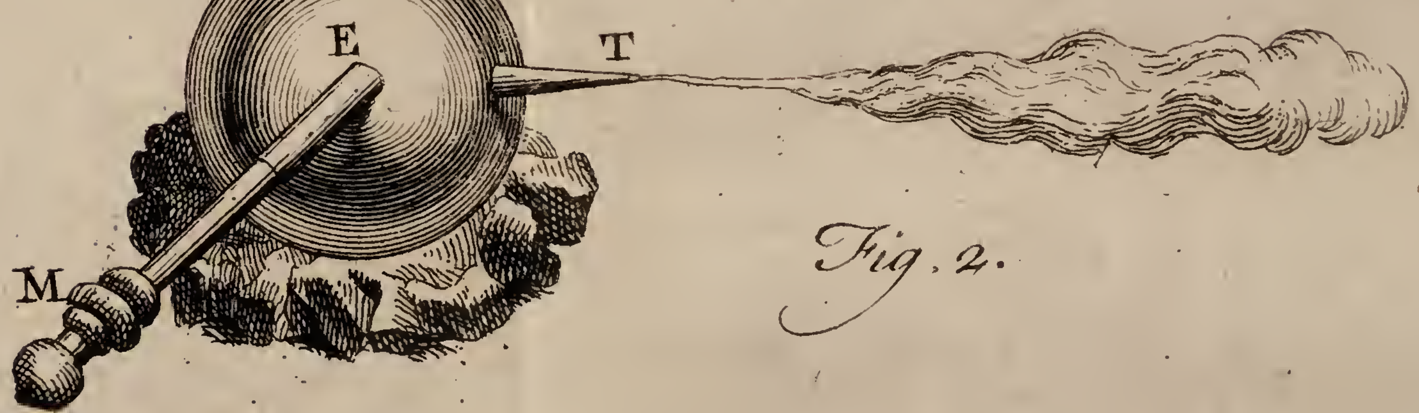


Fig. 2.

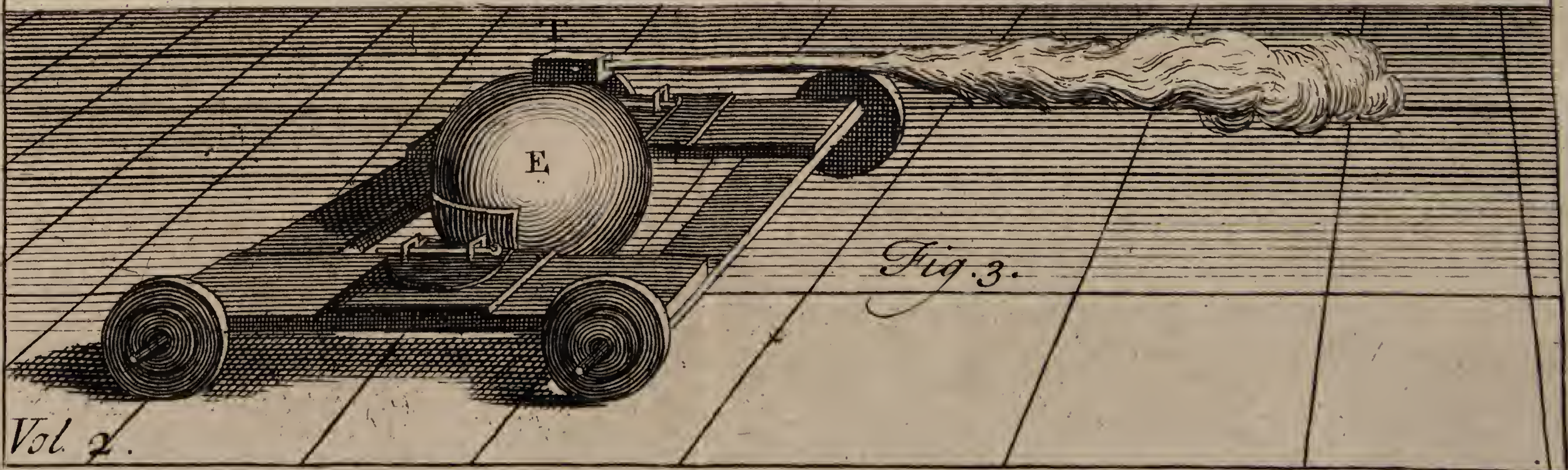


Fig. 3.

Vol. 2.

the Light which comes between thoſe Lines, will be attracted by the Medium X.

At the diſtance of the Line G H, only the extreme Parts of the Medium X act upon the Light; at a leſs Diſtance both they and other Parts act ſo as to encreaſe the attracting Force, when the Diſtance is diminiſh'd, as has been before obſerv'd *. In the denſer Medium X, let the Line I L be ſuppoſed at the ſame diſtance from E F as G H is in the Medium Z. Let the Light enter into the Medium X, and it will on all ſides be attracted by the Particles of the Medium whoſe Diſtances from the Light are leſs than the Diſtance between E F and G H; for the Light is ſuppos'd to be attracted at that Diſtance by the Particles of the Medium X.

As long as the Light is between the Lines E F and I L, the attracting Force is the ſtrongeſt towards I L, becauſe there are more Particles that draw that Way; but as the Number of Particles that act the contrary way encreaſes, that is, as the Diſtance from E F encreaſes, the Force towards I L is diminiſhed, till in the very Line I L the Light be equally attracted every way; which alſo obtains evere where in the Medium X beyond I L.

Suppoſe a Ray of Light to come in the Line A *a*, and fall obliquely on the Surface which divides the Mediums, or rather on the Surface G H, where the Action begins, by which the Light is driven towards the Medium X: when the Ray comes to *a* it is turn'd out of the right Line by the Force by which it is attracted by the Medium X; that is, by which it is driven towards it in a Direction perpendicular to its Surface. And indeed the Ray of Light is bent out of the right Line in every Point, as long as it is between the Lines G H and I L, between which

* 613.

which the ſaid Attraction acts; and therefore between thoſe Lines it deſcribes the Curve *a b*, in the ſame manner that Projectiles move *. Beyond the Line I L the Action which bends the Ray ceaſes; therefore it goes on then in a right Line according to the Direction of the Curve in the Point *b*.

The Diſtance between the Line G H and I L is very ſmall; therefore when we conſider Refraction, we take no notice of the bended Part of the Ray, which we look upon as if it was made up of two ſtrait Lines A C, C B, meeting at C, namely on the Surface which divides the Mediums.

Thro' C draw N C M perpendicular to the Surface of E F.

Definition III.

620 *The Part* A C *of the ſaid Ray, is call'd the incident Ray.*

Definition IV.

621 *The Angle* A C N *is call'd the* Angle of Incidence.

Definition V.

622 *The Part* C B *is call'd the* Refracted Ray.

Definition VI.

623 *The Angle* B C M *is call'd the* Angle of Refraction.

624 In this caſe, *When Light goes out of a rare into a denſe Medium, the Angle of Refraction is leſs than the Angle of Incidence* by reaſon of the Inflexion of the Ray; for theſe Angles wou'd be equal, if the Ray A C continu'd to move ſtrait on in the Line C D. The Ray C B does alſo come nearer to the

Perpendicular C M; and therefore *the Refraction is* ſaid to be *made towards the Perpendicular.*

On the contrary, *If the Ray goes out of a denſer* 625 *into a rarer Medium, it will recede from the Perpendicular,* becauſe the denſer Medium attracts the Ray in the ſame manner, whether it goes out of a rarer into a denſer, or out of a denſer into a rarer Medium. Therefore if B C be the Ray of Incidence, C A will be the refracted Ray; that is, *Let the Ray come from either Side, and it it will move* 626 *in the ſame Lines.* Therefore, *if there be two Rays,* 627 *and one comes out of a denſer Medium into a rarer, and the other out of a rarer into a denſer, and the Angle of Refraction of the one be equal to the Angle of Incidence of the other, the two remaining Angles of Incidence and Refraction will be equal to each other.*

Whence it follows, that *The Direction of the Ray is not chang'd, if it moves thro' a Medium terminated by two Surfaces parallel to each other*; for as much as it is turn'd towards any ſide at its Entrance, ſo much exactly is it turn'd the other way as it goes out of the ſaid Medium.

If a Ray falls perpendicularly on the Surface that ſeparates two Mediums, it will not be turn'd out of the right Line by the Attraction of the denſer Medium; becauſe in that Caſe it acts in the Direction of the Ray.

Plate 4. *Fig.* 2.] To confirm what we have ſaid 630 by Experiments, take a Trough or open Box P, about a Foot long, 4 Inches wide, and of the ſame Depth. Its two ſides *a b c d, a b c d,* are Planes of Glaſs parallel to each other, and this Box muſt be fill'd with Water two Inches and half high.

The Experiments muſt be made in a dark Place; the Light muſt be let in thro' a ſlit in the moveable round Plate O, which is fix'd to the

Window-ſhut, and is eaſily turn'd round, that the Slit may be inclin'd at Pleaſure: the Slit is 4 Inches long and $\frac{1}{8}$ Inch wide.

The Light that is let in, ſtrikes upon the Looking-Glaſs S, and the Slit is ſo inclin'd, and Speculum diſpoſed, that the Beam that comes thro' the Slit, may be horizontally reflected by the Looking-Glaſs, the Beam being in a vertical Poſition, that it may go thro' a vertical Slit in the Board **T**, of the ſame Dimenſions as that in the Plate **O**. This Board is us'd to diminiſh the breadth of the Beam, which is continually encreaſing by reaſon of the Light that comes from the Sides of the Sun.

Experiment 1.] Things being diſpos'd as we have ſaid in the Deſcription of the Machine; let the Beam fall perpendicularly on the Surface *a b c d*, and it will paſs perpendicularly thro' the Water and the upper part of the Trough, and not be turn'd out of the Way at all, either going in or coming out: by which is confirm'd what has been ſaid (N°. *629.*)

Experiment 2.] Now let the Beam fall obliquely on the Surface *a b c d*, at *f g*; the upper Part of the Beam will continue its Motion ſtrait along *h*; but the lower Part of it in the Water, will be bent towards *i*, coming towards the Perpendicular; which confirms (N°. *624.*)

Experiment 3.] Every thing being, as in the former Experiments, the Beam which, at *i*, goes out of Water into Air, is turn'd out of its Way fromwards the Perpendicular, and in ſuch manner as to move in the ſame Direction as the incident Ray that goes into the Water at *g*; for it goes on parallel to the Ray *f h* continued: which confirms (N°. *625*, *626*, and *628*.

In what has been ſaid hitherto, we have only conſider'd the Attraction of the denſer Medium, becauſe it over-powers; but we muſt not overlook the Action of the rarer Medium, becauſe it diminiſhes the Action of the denſer, which action becomes ſo much the leſs on the Rays of Light as the Mediums differ leſs in Denſity. Therefore *there is no Refraction where the Denſities of Mediums are equal; and the Refraction is greateſt where the Denſities of Mediums differ moſt.*

The Laws of Refraction are deduc'd from the Acceleration which the Attraction generates; therefore this Acceleration muſt be examin'd.

DEFINITION VII.

The Space terminated by the Planes G H and I L, is call'd the Space of Attraction. 632

Plate 4. Fig. 1.] The Attraction acts between the Planes repreſented by theſe Lines, but no farther *. * 619.

The Direction of this Action is perpendicular to the Surface that ſeparates the Mediums, and conſequently to the Surface I L; *and its Form is unequal at different Diſtances from that Surface* *. *But it is equal at equal Diſtances*, becauſe both Mediums are ſuppoſed homogeneous, and alike in all their Parts. 633 * 619.

The Motion of the Ray A C may be reſolved into two other Motions, according to the Directions A O and O C *, of which the firſt is parallel to the Surface E F, and the ſecond perpendicular to that Surface: the Celerities of which Motions will be reſpectively proportional to thoſe Lines A O and O C, whilſt A C denotes the Celerity of the Ray itſelf *. * 192. * 192.

634 *The Motion, according to the Direction* A O, *is not chang'd by the Attraction perpendicular to the Surface* I L, *only the Motion according to* O C *is accelerated.*

635 Keeping the Line A C, that is the Celerity of the Ray, its Inclination may be chang'd, whereby alſo the Celerity in the Direction O C is alſo chang'd; which Celerity wholly vaniſhes if the Angle A *a* G be very ſmall. In which caſe, if after Light has enter'd into a denſer Medium, its Motion be reſolv'd into two, ſo that the Direction of the one be perpendicular to the Surface I L, its Celerity muſt be wholly attributed to the Attraction ſo often mention'd. For as it enters into the Space of Attraction, a Motion is generated in that Direction; and as it goes thro' that Space, in which a new Action does every where act upon the Light in the ſame Direction, it is continually accelerated. Which Acceleration obtains in every Paſſage of Light thro' the Space of Attraction; but it is different according to the different Celerity with which Light comes perpendicularly to the Surface which parts the Mediums.

If the Attraction was equable thro' the whole Space of Attraction, the Laws concerning the ſaid Attraction might be determin'd (as was ſaid of the Acceleration of heavy Bodies after N° 130.) by help of the rectangular Triangle P Q R, (*Plate* IV. *Fig.* 3.) in which the Lines parallel to the Baſe repreſent the Celerities, whilſt Portions of the Area of the Triangle repreſent the Spaces gone thro'.

But here we have always the ſame Space run thro', namely the Breadth of the Space of Attraction, becauſe we only conſider the Motion which is perpendicular to the Surface which ſeparates the Mediums; therefore that Space is always repreſented by equal Parts of the Area of the Triangle P Q R. Let P *d c* repreſent ſuch a

Part when the Celerity is equal to o. The Light enters the Space of Attraction in the abovemention'd perpendicular Direction, that is, when an incident Ray makes a very ſmall Angle with the Surface that ſeparates the Mediums; $d\,c$ in that Caſe will denote the Celerity acquir'd by the Attraction, and with which the Light goes out of the Space of Attraction.

But if the Light goes perpendicularly into the Space of Attraction with the Celerity that is expreſs'd by $f\,g$, it will go out of that Space with the Celerity $h\,i$, ſuppoſing the Areas P$d\,c$ and $f\,g\,i\,h$ equal to one another, as appears from what has been ſaid. The Triangles P$d\,c$, P$f\,g$, P$h\,i$ are Similar, and therefore their Areas are to one another as the Squares of the homologous ſides $d\,c$, $f\,g$, $h\,i$; but the Sum of the Areas P$d\,c$, P$f\,g$, is equal to the Area P$h\,i$, (by reaſon of the equal Areas P$d\,c$ and $f\,g\,i\,h$;) therefore alſo the Sum of the Squares of the Lines $d\,c$ and $f\,g$ is equal to the Square of the Line $h\,i$; whence it follows, that with the three Lines abovementioned one may form a rectangular Triangle, whoſe Hypothenuſe will be $h\,i$.

636 Therefore, *In a rectangular Triangle, one Side of which is the Celerity with which Light enters the Space of Attraction perpendicularly, and the other ſide the Celerity acquir'd in going thro' that Space, when the Celerity with which the Light enters into it is equal to* o; *the Hypothenuſe of the Triangle will be the Celerity with which the Light goes perpendicularly out of the Space of Attraction on the other Side:* Which univerſally obtains, which way ſoever the Attraction is chang'd, in the Space of Attraction according to the different Diſtance of the Planes that terminate that Space. Which to prove,

Let us ſuppoſe the Space of Attraction to be divided into two Parts, whether equal or unequal, by a Plane parallel to the Surfaces with which it is terminated. Let us ſuppoſe beſides, that the Attraction is not the ſame in thoſe two Parts, but yet that it does not vary in one of them. Theſe Parts are to be conſidered as two different Spaces of Attraction. Let A (*Plate* IV. *Fig.* 4.) be the Celerity which the Light acquires in going thro' the firſt part of the Space, when it enters the Space with the Celerity O. Let B be the Celerity acquir'd in going thro' the ſecond Part of the Space when the ſame Light enters that Part with the Celerity O. It is to be obſerv'd that this Demonſtration relates to the Motion perpendicular to the Surface which ſeparates the Mediums.

Let the Light enter the firſt Part of the Space abovemention'd with the Celerity O, it will come to the ſecond with the Celerity A; if therefore a right-angled Triangle be form'd with the Sides A and B, the Hypothenuſe E D will expreſs the Celerity with which the Light will go out of the
* 636 Space of Attraction *.

If the Light enters the Space of Attraction with the Celerity F G, let the rectangular Triangle H F G be drawn with the Sides F G and A; the Hypothenuſe H G will be the Celerity, with which the Light goes out of the firſt Part of
* 636 the Space of Attraction *, and enters into the Second; and if you draw the rectangular Triangle H G I, whoſe Perpendicular is equal to the Line B, you will have the Hypothenuſe I G to denote the Celerity with which the Light goes out, and continues its Motion after it has run
* 636 thro' the whole Space of Attraction *.

Now we muſt demonſtrate that the Celerity I G, is alſo the Hypothenuſe of the rectangular Triangle N M L, whoſe Side M L is equal to the Celerity F G, with which the Light enters the

Space of Attraction; and whoſe other Side L N is equal to the Line E D, which is the Celerity that the Light acquires in going thro' the whole Breadth of the Space of Attraction, when it has enter'd it with the Celerity O; which being alſo demonſtrated in that Caſe, in which two different Forces of Attraction act, it is plain that the Propoſition of N°. *636* is thereby prov'd.

But it is plain from the Conſideration of the rectangular Triangles, that the Lines I G, and N M are equal. The Square of the Line N M, is equal to the Squares of the Lines N L and L M or F G: N L is equal to the Line E D, whoſe Square is equal to the Squares of the Lines E C and C D, or of the Lines A and B, which are equal to F H and H I: therefore the Square of the Hypothenuſe N M is equal to the three Squares of the Lines F G, F H, and H I. To which three Squares the Square of the Line G I is equal; as having been prov'd equal to the Squares of the Lines H I and H G, which laſt is equal to the Squares of the Lines H F and F G.

If the ſpace of Attraction be divided into ever ſo many Spaces by plane parallel Surfaces, which terminate that Space, and the different Parts have different Forces of Attraction, the ſame Demonſtration will ſerve; and the number of Diviſions may be made any how *in infinitum*; which Caſe obtains in the Refraction which Light ſuffers going out of any Medium into another of different Denſity *; *to* which *Refraction* 637
therefore *the Rule of* N°. *636 may be applied.* * 633

Plate IV. *Fig.* 5.] Let Z be the rarer, and X the denſer Medium, and let them be ſeparated by the Plane E F; let a Ray of Light A C fall obliquely on the Surface E F; let A C denote the Celerity of the Light in the Medium Z, and let that Line A C be ſettled; that is, let it be always the ſame, whatever the inclination of the Ray is. With the Center C and the Semidiameter C A draw a Circle; and let N C M be drawn perpendicular to E F; from A, draw A O perpendicular to N C, and A Q to E F.

Let us conceive the Motion along A C re-
ſolv'd into two others, the one along A O, and
* 192 the other along A Q or O C*; the Line O C
will denote the Ray's Celerity perpendicular to the
Surface E F, which Celerity alone is encreaſed
* 634 by the Attraction of the Medium *.

Let C P be the Celerity which Light acquires
in paſſing perpendicularly thro' the Space of At-
traction of the Medium X; ſuppoſing the Cele-
rity of Light at its entrance to be O, the Hypo-
thenuſe O P of the rectangular Triangle P C O
will be the Celerity of the Ray A C in the
Medium X, according to a Direction perpendi-
* 637 cular to the Surface E F *; the Celerity of the
Light in the Direction A O or Q C, parallel to
* 634 the Surface E F is not chang'd *. Therefore let
C V be equal to A O or Q C, and V B per-
pendicular to EF, equal to the Hypothenuſe PO,
and draw C B; the Motion along C B is com-
pounded of the Two, and this Line by its Situ-
ation determines the Direction, and by its length
638 *the Velocity of the Light in the Medium* X *; which
* 190 Celerity *is not chang'd by the different Inclination of*
the Ray A C. For the Square of the Line C B is
equal to the Square of the Line B V or P O,
the Square of the Line C V or A O; but
the Square of the Line P O is equal to the
Squares of the Lines P C and C O: therefore the
Square of the Line C B is equal to the three
Squares of the Lines P C, C O and A O; which
two laſt, if joyn'd, will give us the Square of the
Semidiameter A C or C N; that is, C B is equal

to P N, whoſe Square is alſo equal to the Squares of the Lines P C and C N, and which undergoes no change from the different inclination of the Ray A C.

The Line C B does in T cut the Circle which is deſcrib'd with the Semidiameter C A; from the Points B and T, draw B S and T R perpendicular to C M; by reaſon of the Similar Triangles C B S, C T R, B C will be to T C or C A, as B S to T R; which Lines therefore, by reaſon that B C and C A are ſettled, will have the ſame Ratio to one another, whatever be the Angle of Incidence. T R is the Sine of the Angle of Refraction T C R, and B S which is equal to C V, that is equal to A O, is the Sine of the Angle of Incidence A C O.

Therefore *in every inclination of the Incident Ray,* 639 *there is a ſettled and conſtant Ratio between the Sines of the Angles of Incidence and Refraction.*

Now ſince B C and C A, which are as the Sines abovemention'd, do alſo denote the Celerities of the Light in *the* Mediums X and Z, it follows that thoſe *Sines are inverſly as the Celerities in the Mediums.*

If the Medium Z be Air, and X Water, the 640 aforeſaid Sines are as 4 to 3; and the Celerity of the Light in Air is to its Celerity in Water, as 3 to 4. But if Z being ſtill taken for Air, X be Glaſs, the Sines will be as 17 to 11. One Experiment determines this for all Mediums.

The Ratio between the Sines of any Angles is the inverſe Ratio of the Secants of the Comple- 641 ments, as it appears in this Figure, ſuppoſing a Circle drawn with the Semidiameter C Q or C V; for then A C (which is equal to C T) and C B will be the Secants of the Angles A C Q and B C V Complements to the Angles of Incidence and Refraction, and inverſly, as B S (which is equal to A O) and T R, which are the Sines of Incidence and Refraction in the greater Circle.

And this Proportion of the Secants gives us a Method of eaſily reducing to Experiment the *Prop.* of N° *639.*

Experiment. IV. *Plate* IV. *Fig.* 6.] In this Experiment the Light is to be let into the dark Chamber thro' a Slit, in the ſame manner as in the former Experiments, and by means of a Looking-Glaſs reflected thro' the vertical Slit in the Board T.

Take a Trough P, nearly of the ſame ſize as that which was us'd in the former Experiments, but which has only one end of Glaſs, namely the little Side *a b c d.* And let it be half fill'd with Water.

The vertical Beam of Light being made to fall obliquely on the Glaſs End of the Trough, the Part of it which is above the Water goes directly forwards, and at *h* falls upon one of the long Sides of the Trough; but that Part of the Beam which is refracted in the Water, goes along *g i,* and ſtrikes againſt the ſame Side of the Trough at *i.* Whatever the Angle be which the Beam makes with the End or Side *a b c d,* the Lines *f h* and *g i* will always be to each other as 3 to 4; as is very eaſily ſhewn in ſeveral Inclinations, if you have two Scales, each with ſmall Diviſions on them; which Diviſions in the one muſt be to the Diviſions in the other, as 3 to 4: For the greater Line *g i,* will always contain as many of the great Diviſions as the leſſer Line *f h* will contain of the ſmall ones. The Angle, which *f h* makes with the Plane *a b c d,* is the Complement of the Angle of Incidence to a right Angle, and the Angle made by the Line *g i* with the ſame Plane is the Complement of the Angle of Refraction to a right Angle; therefore *g h* and *g i* are the Secants of the Complements of the Angles of Incidence and Refraction, which have a conſtant Ratio to one another as this Experiment.

We have hitherto conſider'd a Ray of Light going out of a rarer into a denſer Medium, but the ſame conſtant Proportion of the Sines mention'd, N° *639*, holds good alſo in the contrary Motion of the Rays; the Angles A C N, M C B (*Plate* IV. *Fig.* 5.) are not chang'd, whether the Incident Ray be A C or B C *. In that caſe, if B C be the Celerity of the incident Ray, C A will be the Celerity of the refracted Ray; for the Motion of the Ray going out of X into Z, is retarded in the ſame manner by the Attraction towards the Medium X, as it is accelerated in the contrary Motion. 642

* 626

CHAP. VII.

Of the Refraction of Light, when Mediums are ſeparated by a plane Surface.

DEFINITION I.

RAys *proceeding from the ſame Point, as a Center, and continually receding from each other, are ſaid to be* divergent. 643

DEFINITION II.

Thoſe diverge more, *which make a greater Angle with each other.* 644

DEFINITION III.

645 *The Point from which the divergent Rays proceed, is call d the* radiant Point.

646 *The more the Rays diverge, ſuppoſing them at equal diſtances from each other, the leſs is the radiant Point*
647 *diſtant from them; and ſo on the contrary,* the Rays are often mov'd by *Refraction*, as if they came from a radiant Point, tho' they do not really proceed from ſuch a Point; that is, if the Rays ſhou'd be continu'd or produc'd back the way from whence they come, they wou'd meet in one Point. In that caſe alſo the Rays are ſaid to be divergent.

DEFINITION IV, and V.

648 Rays *which concur in one Point, or wou'd concur if they were continued, are ſaid to be* convergent;
649 *and thoſe are* more convergent *which make greater Angles between themſelves.*

DEFINITION VI.

650 *The Point of the Concourſe of converging Rays, is call'd the* Focus.

DEFINITION VII.

651 *The Point, in which converging Rays, and ſuch as (being intercepted or turn'd out of the Way before their Concourſe) wou'd have concurr'd, being continued, is call'd the* imaginary Focus. Which name is alſo given to that Point from which thoſe divergent Rays are conceiv'd to flow, which do not pro-
* 647 ceed from the radiant Point *.

652 *The more the Rays converge, ſuppoſing their diſtance from each other to be the ſame, the leſs diſtance from them is the Focus, whether real or imaginary.*

If

Fig. 4.

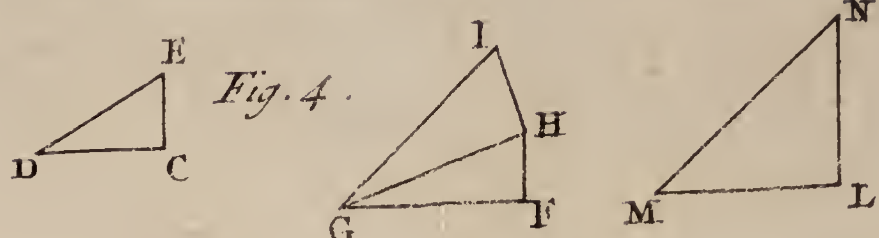

E
D
C
I
H
G
F
N
M
L

Fig. 1.

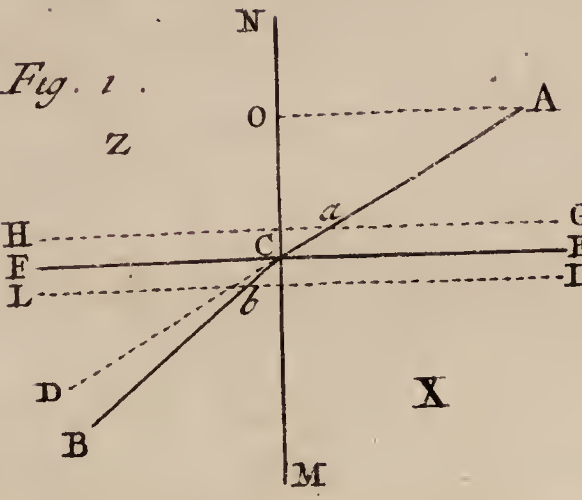

N
O
A
Z
a
G
H
C
E
F
I
L
b
D
B
X
M

Fig. 3.

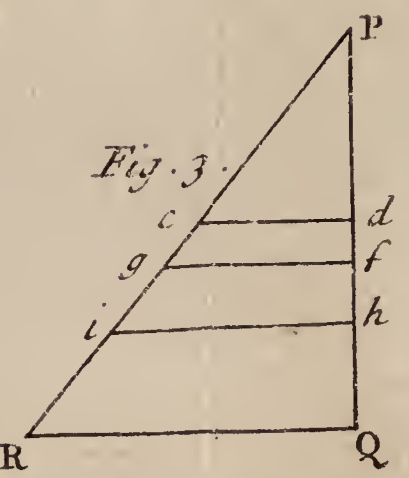
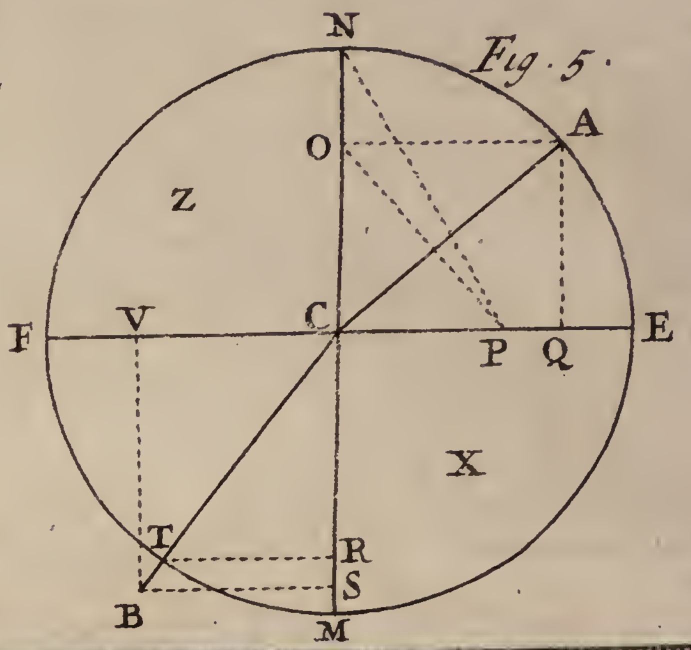


Fig. 5.


N
O
A
Z
F
V
C
P
Q
E
X
T
R
B
S
M

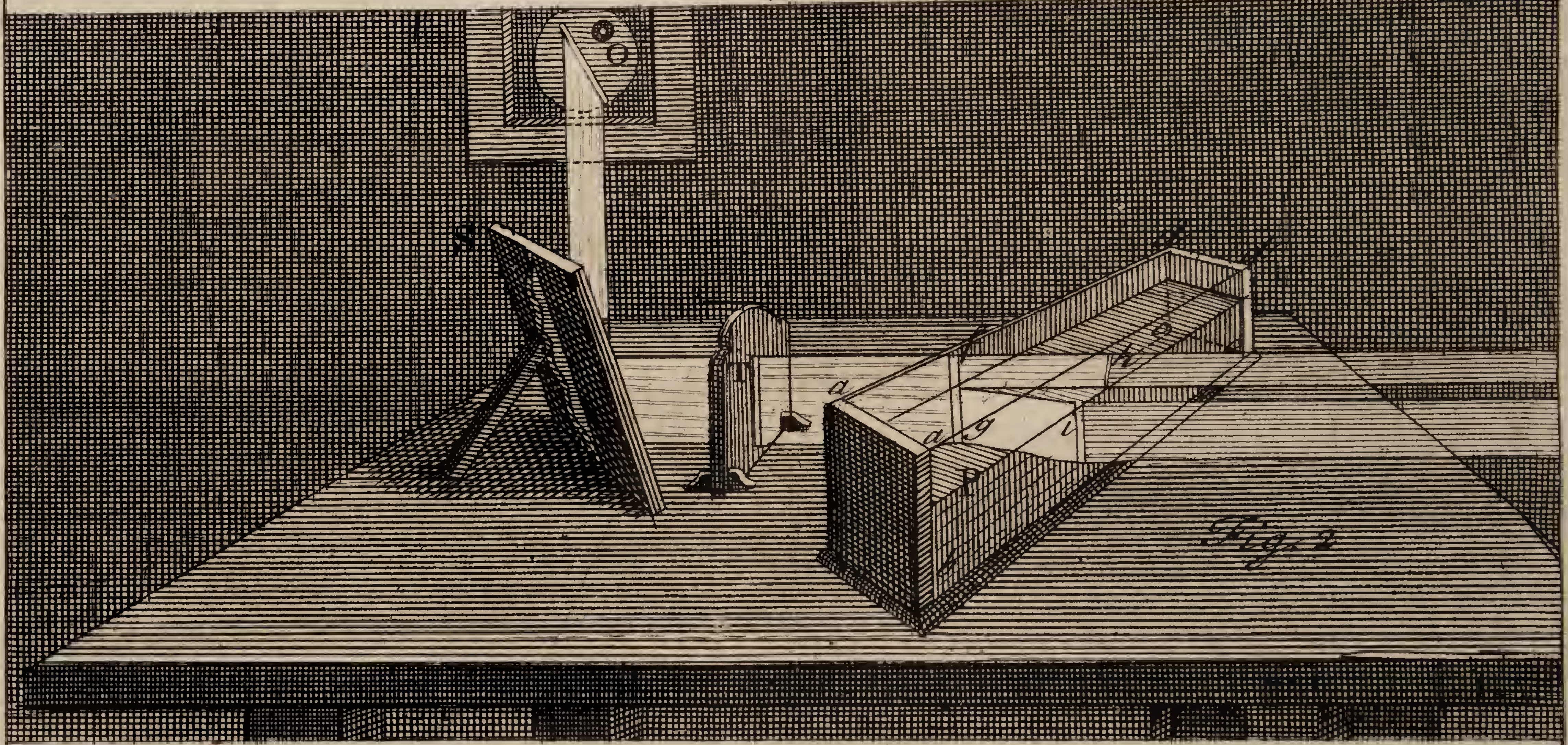

O
S
T
a
d
g
h
o
i
P

Fig. 2

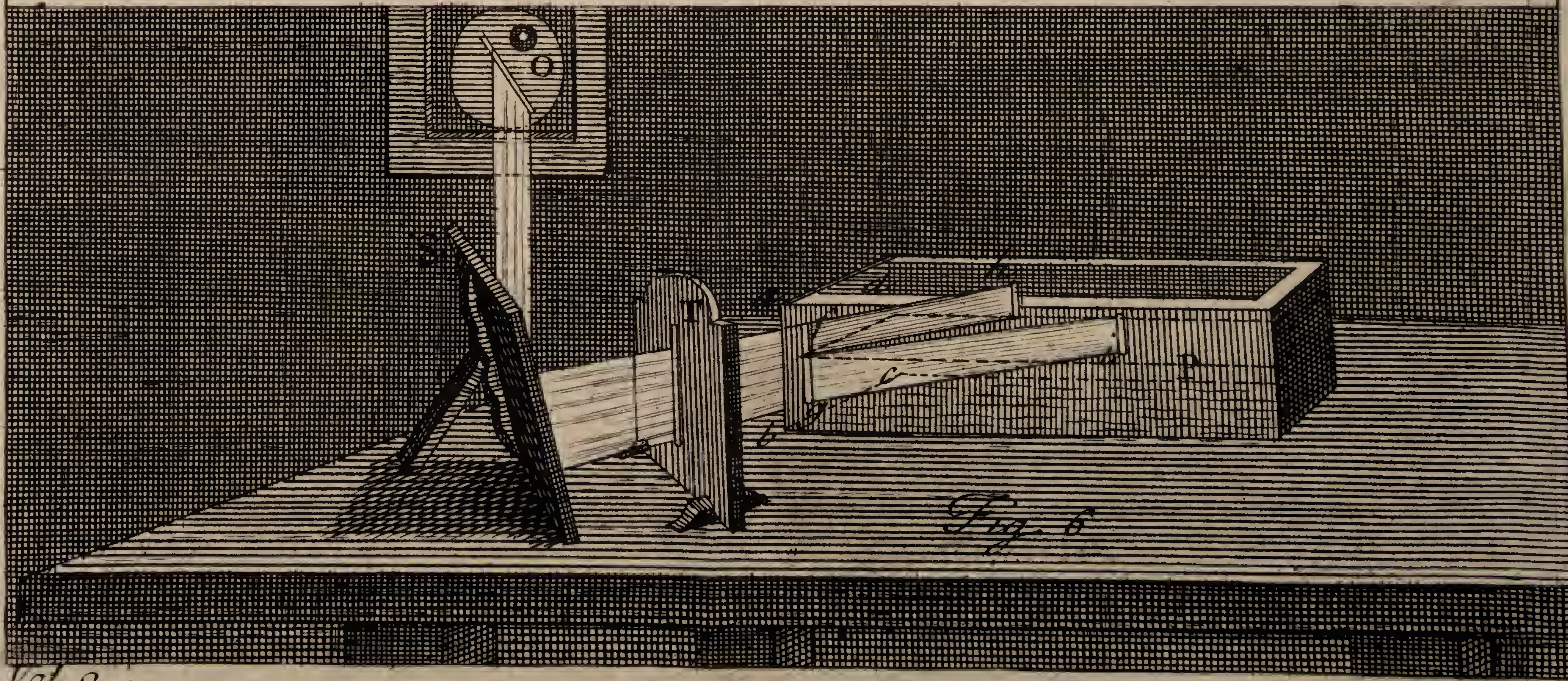


Fig. 6

653 *If parallel Rays paſs out of any Medium into another of different Denſity, they will alſo be parallel after Refraction:* Becauſe they are all equally inflected; for in all this Chapter we ſpeak of Mediums ſeparated by a Plane Surface.

654 *Let* X *and* Z *be two Mediums, the laſt more rare, and the other more denſe, ſeparated by the Plane* E S, *(Plate* V. *Fig.* 1.) *from the Point* R *let there proceed the divergent Rays* P C, R *o*, R *n*, *and enter into the denſer Medium:* Let one of them be R C, perpendicular to the Surface E S; this laſt is not turn'd out of the way *, but continues its * 629 Motion along C G. The Rays R *o*, R *n* are refracted towards Perpendiculars which are conceiv'd to fall upon the Surface E S in the Points *o* and *n* *. *Theſe Rays are mov'd in the denſer* * 624 *Medium, as if they all proceeded from the imaginary Focus r, which is farther diſtant from the Surface than* R, *if the Rays are not too much ſcatter'd*; which yet is not to be underſtood Mathematically; for by a Point we underſtand a ſmall Space, ſuch as is otherwiſe call'd a Phyſical Point.

To demonſtrate this Propoſition, we muſt conſider, that the Angle R *o* C is the Complement of the Angle of Incidence to a Right-Angle; and that the Angle *r o* C is alſo the Complement of the Angle of Refraction to a Right-Angle; and therefore that the Lines R *o*, *r o*, are the Secants of the Complements of the Angles of Incidence and Refraction, ſuppoſing the Semidiameter to be *o* C; between which Secants there is a conſtant Proportion *. In the ſmall * 641 Divergence R *o* and R C, as alſo *r o* and *r* C, 639. they do not ſenſibly differ, and between R C and *r* C the Ratio is always conſtant; that is, *r* is fix'd as well as R, tho' the Inclination of the Ray be chang'd: And therefore R*n* is refracted along *n*A, as if it had proceeded from *r*.

655 *If the Rays are too much diſpers'd*, this Demonſtration will not ſerve, and the Place of Concourſe *r* cannot be taken for a Point: In this Caſe *a little Circle muſt be imagin'd* there, *into which all the Rays concur, which will be the greater, the greater the Angle is that the divergent Rays make.*

656 *If ſome Rays proceeding from* R *are not too much diſperſed, but fall very obliquely on the Surface* E S, *they will be refracted, as if they proceeded from a Point not very remote from the Point r*: As is plain from what has been ſaid.

657 *The Rays*, ſuch as A*n*, B*o*, G C, *which come converging from a denſer Medium* X *into a rarer* Z, concur ſooner than they wou'd do, if they ſhou'd *625 continue their Motion in a denſer Medium *; that is, *become more convergent*, and the real Focus is leſs diſtant than the imaginary one. In this Figure the imaginary Focus is *r*, and the *652 real Focus R *. This Propoſition therefore is properly the Inverſe of the Propoſition of N°: 654. *626 and therefore * both are prov'd by the ſame Experiment.

Experiment 1. *Plate* V. *Fig.* 2.] Thro' the Ball G, which is moveable in the Window-ſhut, and has an Hole going thro' the middle of it, let a cylindric Beam of the Sun come into the dark Room, and be reflected horizontally by the Looking-Glaſs S; let it then go thro' the Convex Lens of Glaſs that is fix'd in the Board or Stand T, and the Rays will meet together at R, and beyond R will move as if they proceeded from that Point; which therefore is the radiant Point.

Convex Lenſes of Glaſs are very common; we ſhall hereafter mention their Properties *, it being needleſs to do it in this Place: Now we only want a radiant Point, and it is enough to ſhew how to make it. * 691 697.

Take a Trough Box P, whoſe Side *a b c d* is of Glaſs, and let it be fill'd with Water: The Rays which diverge from the Point R become leſs diverging when they go into the Water.

658 *When convergent Rays,* as HD, I*p*, L*q* (*Plate* V. *Fig.*1.) having their imaginary Focus at *f*, *go from a rarer Medium* Z *into a denſer* X, *they become leſs convergent**, and concur in the Focus F, which is more diſtant from the Surface ES *, as appears by applying here the Demonſtration given in N°. 654. * 624 * 652

Rays proceeding from the Point F, *and going out of a denſer Medium into a rarer, become more diverging,* and move as if they came from *f*; which Propoſition is the inverſe of the foregoing, and is confirm'd by the ſame Experiment *. * 626

Experiment 2. *Plate* V. *Fig.* 3.] Take the ſame Box P as was uſed in the former Experiment; but here let in two Beams of the Sun into the dark Room through two Holes in the moveable Plate in the Window-ſhut; let them be both reflected horizontally, and tranſmitted through ſimilar convex Lenſes; thereby the Rays of the Beams will become convergent, having their Focus's at the ſame Diſtance; but if the converging Rays are made to run into the Water in the Box thro' the Side *a b c d*, they will be collected at a greater Diſtance; which will plainly appear by comparing together the Situation of the Points F in the Air, and *f* in the Water.

CHAP.

CHAP. VIII.

Concerning the Refraction of Light, when a ſpherical Surface ſeparates the Mediums.

Plate VI. *Fig.* 1.] LET X and Z be Mediums differing in Denſity, the laſt the rarer, and the firſt the denſer; let them be ſeparated by the ſpherical Surface E S, whoſe Center is C, and whoſe Convexity is towards the rarer Medium.

660 To begin, by examining the moſt ſimple Caſe; *Let us ſuppoſe parallel Rays*, as B O and A *n*, *going out of a rarer into a denſer Medium, and falling upon a convex Surface*, ſuch as we have juſt deſcrib'd; let one of them be B O, which being continu'd, goes thro' the Center, and falls perpendicularly upon the Surface E S; and there-
* 629 fore is not turn'd out of the right Line *. All *the Rays which are not too diſtant* from that Ray come nearer to it by the Refraction of the denſer Medium, and *are collected into one Point* F: As for Example; Let A *n* be a Ray which is refracted along *n* F; thro' the Point *n* draw to the Center C the Semidiameter C *n*, and let it be continu'd to *p*; as this Line is perpendicular to the Surface which ſeparates the Mediums, the Angle of Incidence is A *n p*, which is equal to the Angle *n* C O; the Angle of Refraction is C *n* F. If the Arc *n* O be a very ſmall one, theſe Angles are as their Sines, whoſe Ratio is
* 639 conſtant *. Therefore theſe Angles *n* C O and C *n* F are increas'd and diminiſh'd in the ſame Ratio, as alſo their Difference, which is the Angle *n* F O, which conſequently follows the Proportion of the Arc *n* O, which is the meaſure of the Angle *n* C O; as long as the Arc *n* O does

Plate 5

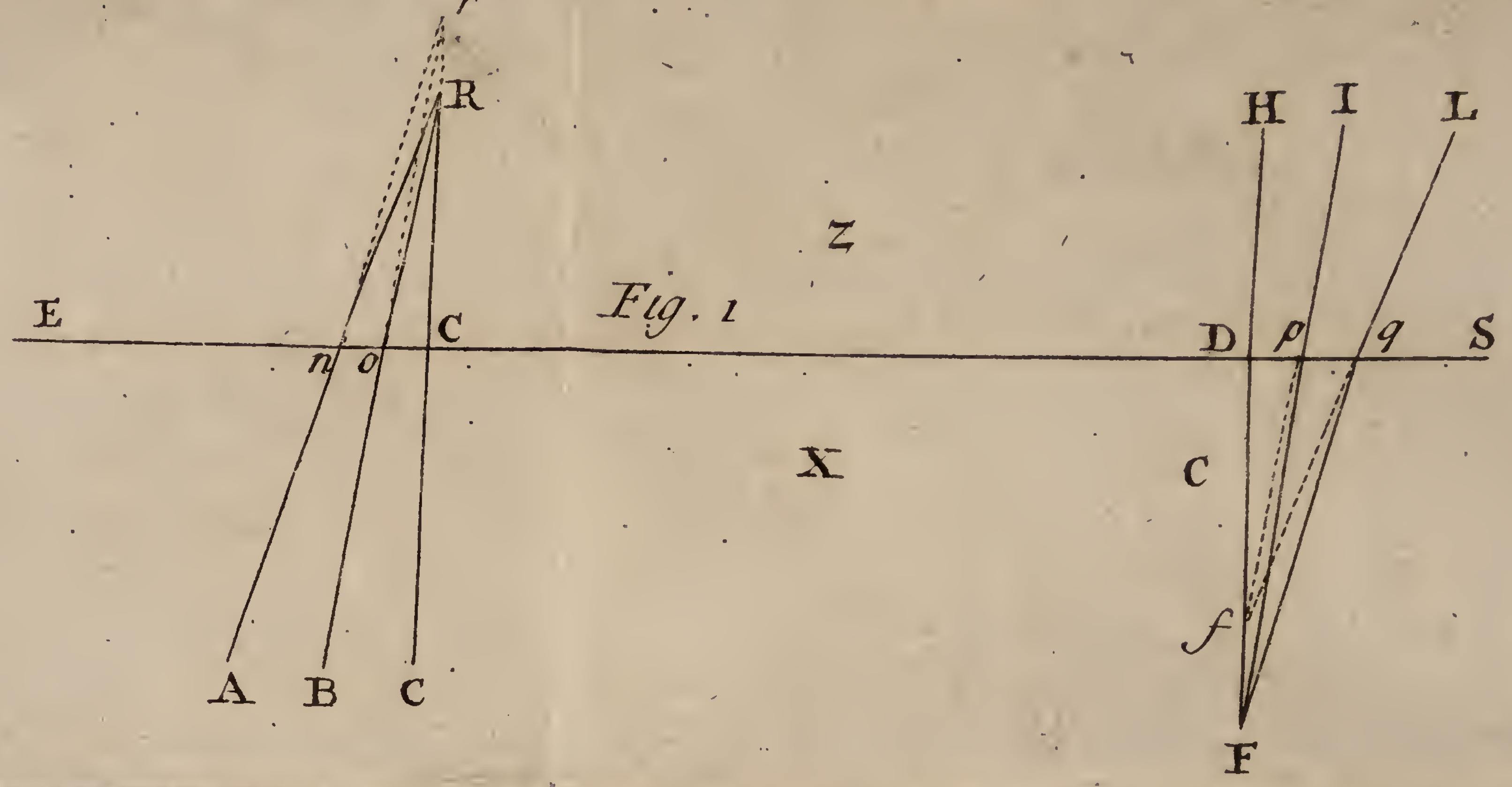


Fig. 1
r
R
Z
E
C
n
o
D
p
q
S
X
C
H
I
L
f
F
A
B
C

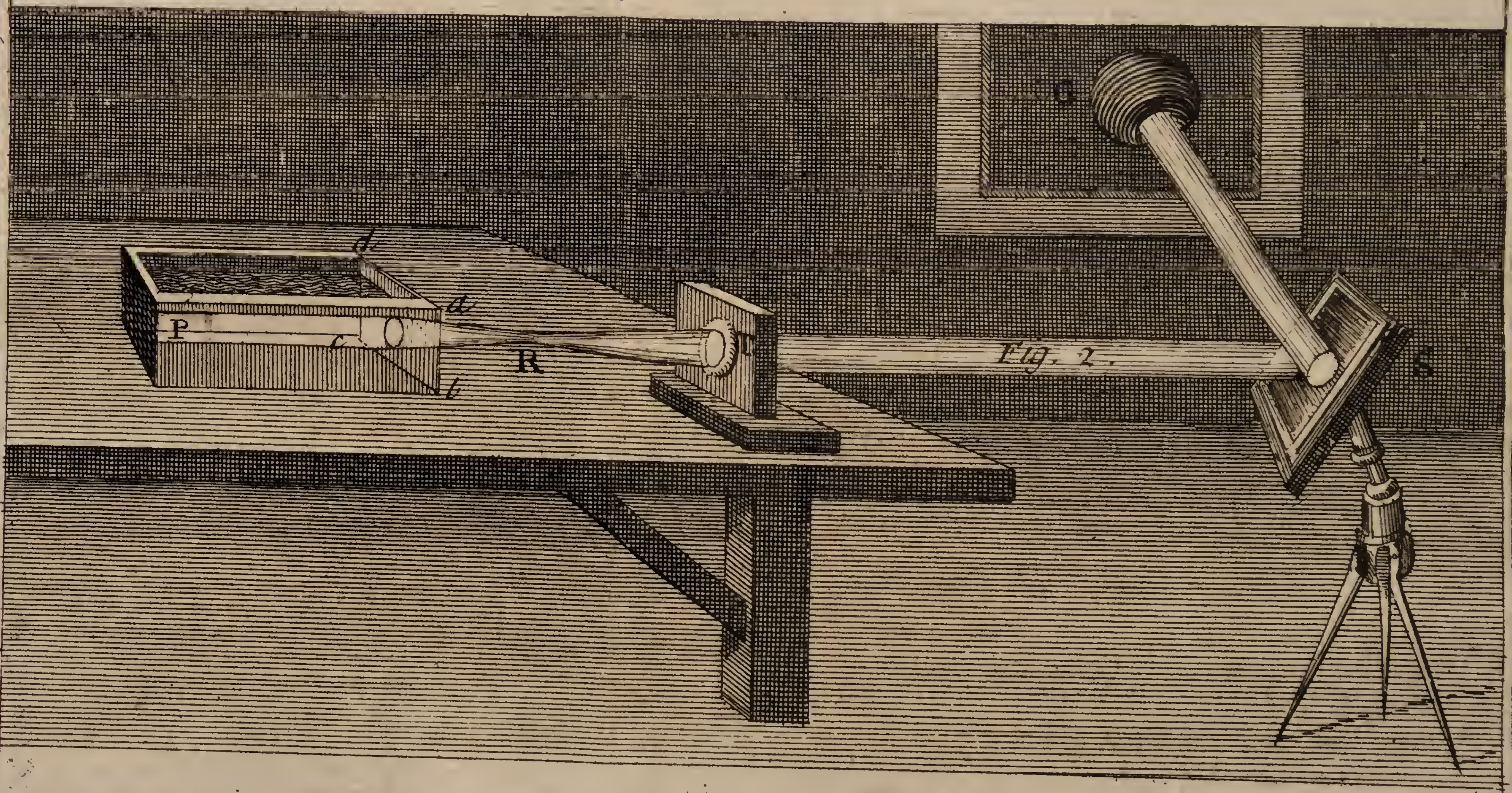


Fig. 2.

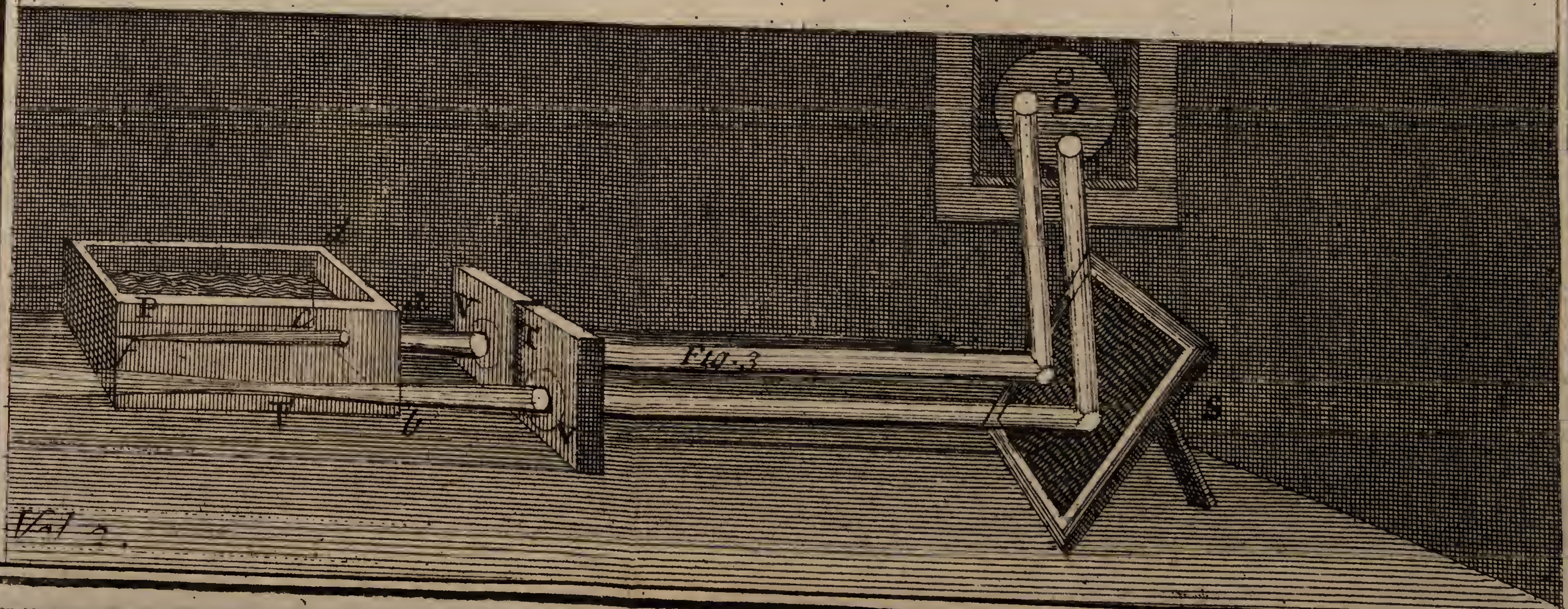


Fig. 3

does not exceed 15 Degrees, the Angle *n* F O is increaſed and diminiſhed ſenſibly in the ſame Ratio as the ſaid Arc; and therefore all the Rays between A *n* and B O, do by their Refraction meet ſenſibly in the Point F.

Experiment 1. *Plate* VI. *Fig.* 2.] Let a cylindric Beam of the Sun, of an Inch in Diameter, made up of an innumerable Quantity of parallel Rays (which are ſo on account of the Sun's immenſe Diſtance) be let into the dark Room, as in the firſt Experiment of the foregoing Chapter, and be reflected horizontally by the Looking-Glaſs S.

Fill with Water the Trough P, which is about 3 Inches high, and as wide, and one Foot long. Let it have a Glaſs V made faſt in one of its Sides: This Glaſs muſt be a Portion of a Sphere, thin, and every where of the ſame Thickneſs, ſuch as the Cryſtal of a Pocket-Watch.

The Convex part of the Glaſs V muſt be outwards, that the Water next to it in the Trough may put on a ſpherical Surface. If the Rays above-mention'd go into the Trough thro' this Glaſs, becauſe the Glaſs is thin, and has its Surfaces parallel, there is no ſenſible change in the Motion of the Light by the Refraction of the Glaſs, and the Light enters into the Water in the ſame manner as if there was no Glaſs. Let the Trough be ſo diſpos'd, that one of the Rays may paſs thro' the Center of the ſpherical Surface, and the others will come nearer and nearer to it, and at laſt concur with it at F.

Plate VI. *Fig.* 3.] Again, let X be the denſer Medium, and Z the rarer, and let them be ſeparated by the ſpherical Surface E S, whoſe Center is at C, and whoſe Convexity is towards the rarer Medium: *From the radiant Point* R *let Rays pro-* 661.

ceed, and enter into the denſer Medium thro' the Surface above-mention'd; ſo that of thoſe Rays, that which is expreſs'd by RO, being continued, may paſs thro' the Center; this Ray is not refracted as it goes into the Water, and all the reſt of the Rays come towards it by the Refraction, *and when they are not too divergent are collected into one Point* as F, in the ſame manner as was ſaid of parallel Rays; with this difference, that the Focus F in that Caſe is more diſtant. The ſame Demonſtration will alſo ſerve here as relates to parallel Rays, which is built upon this Foundation, that the Angle of the Incidence increaſes in the ſame Ratio as the Arc *n* O, which does alſo obtain here, when the ſaid Arc does not exceed 15 Degrees. Let R*n* be a Ray of Light, and from the Center C thro' *n* draw C*np:* The Angle R*np* will be the Angle of Incidence; let it be divided into two parts by the Line *nq*, parallel to the Line ROC; the Part *pnq* is equal to the Angle *n*CO, which is meaſur'd by the Arc *n*O, and which therefore follows the ſame Proportion as that Arc; and which alſo the Angle *n*RO (if it be very ſmall) does follow, and is equal to the ſecond part of the Angle of Incidence, which alſo does wholly increaſe and diminiſh in the ſame Ratio as the Arc *n*O; for the Ratio which holds in reſpect of every Part taken ſingly, will alſo hold in reſpect of the whole.

662 The ſame Demonſtration may be applied to any diverging or converging Rays, which in any Caſe are refracted in paſſing thro' a ſpherical Surface; and which (as appears by this Demonſtration) when they diverge but little, have their Focus real, or imaginary, or run parallel. It is enough to have obſerv'd this in general.

The Focus F *of the Rays that come from* R, *goes farther off when* R *is brought nearer; and ſo on the contrary.* For the radiant Point being brought nearer, if the Point *n* remains the ſame, the Angle of Incidence is increas'd; and as it increaſes, ſo does alſo the Angle of Refraction F*n*C, and *n*F interſects RC at a greater Diſtance. 663

Experiment 2. *Plate* VI. *Fig.* 4.] This Experiment differs from the foregoing only in this, that a Cylindric Beam of the Sun reflected horizontally, muſt be tranſmitted thro' the Convex Lens in the Board **T**, as was done in the Experiments of the foregoing Chapters, to form the radiant Point R, from which the Rays going forward diverging, are collected in the Water at a greater Diſtance than if they had been parallel.

As you move the Board **T**, the Point R alſo changes its Place: If this Point is farther off from the Surface that ſeparates the Mediums, F falls nearer to it: On the contrary, if R be nearer, **F** is farther off.

The radiant Point may be brought ſo near to the Surface above-mention'd, that the Focus will recede to an infinite Diſtance; that is, *that the refracted Rays will run parallel.* 664

Experiment 3. *Plate* VI. *Fig.* 5.] Things being diſpos'd as in the former Experiment; by removing the Board **T**, let R be brought nearer to the Trough; and it may eaſily be ſo diſpos'd, as to make the refracted Rays become parallel.

Experiment 4. *Plate* VII. *Fig.* 1.] Now if the Experiment be repeated, *bringing nearer* to the Trough *the radiant Point* R, *the refracted Rays will become divergent; but they will diverge leſs than the* 665

666 *the incident Rays. If the Rays, which out of a*
rarer enter into a denſer Medium thro' a convex
Surface, be converging and directed towards the
Center of that ſpherical Surface, they will ſuffer no
* 629. *Refraction* *. *But if they be directed towards another*
667 *Point*, ſince they are refracted towards the
* 624. Perpendicular *, they will be ſo inflected, that the Focus of theſe converging Rays will always be between the Center of the Surface which ſeparates the Mediums (to which all the Perpendiculars are directed) and the Point to which the incident Rays tend. *That is, if the imaginary Focus of the incident Rays* be at a leſs Diſtance than the Center, the refracted Rays will be leſs converging: But if this imaginary Focus *be beyond the Center, the refracted Rays will be more converging.*

Experiment 5. *Plate* VII. *Fig.* 2.] Every thing being in the ſame manner as in the former Experiments, it is eaſy to confirm theſe Propoſitions by Experiments; for the Board **T** may be ſo diſpos'd, that the convergent Rays ſhall enter the Water, ſo as to have their imaginary Focus at any Diſtance in it.

From what has been ſaid hitherto it is eaſy
668 to determine what happens *in a contrary Motion*
*626. *of the Rays* *; that is, the Motion of the Rays from a denſer into a rarer Medium, *the convex Surface remaining towards the rarer Medium.*

*644. *Parallel Rays after Refraction concur in a Focus* *.
669 *The Rays that come from a radiant Point meet* alſo
*661. *in a* Point or *Focus* *, and as that Point is
brought near, the Focus goes farther off; and
663. ſo the reverſe on the contrary *.
670 *The radiant Point may be ſo plac'd, as that* the
Focus ſhall fly out to an infinite Diſtance; that
* 660. is, *the Rays will become parallel* *.

If

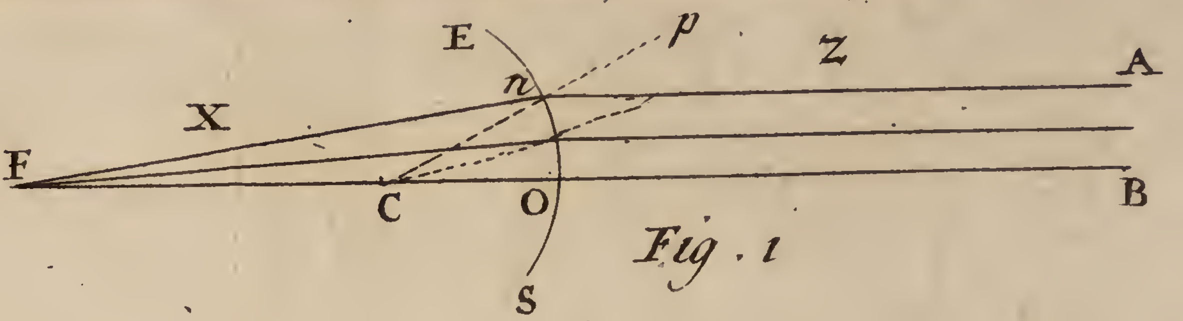

E
p
Z
A
n
X
F
C
O
B
S

Fig. 1

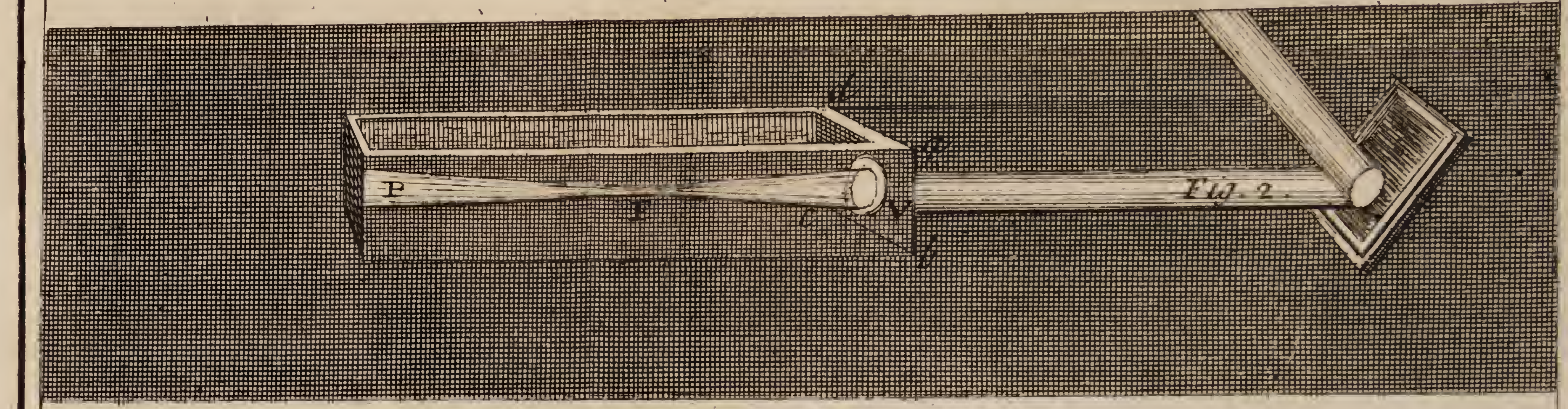


Fig. 2.

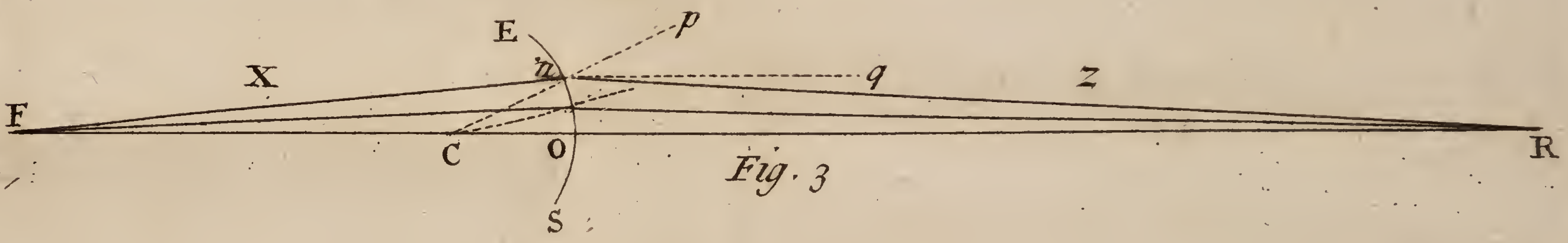

E
p
X
n
q
Z
F
C
O
R
S

Fig. 3

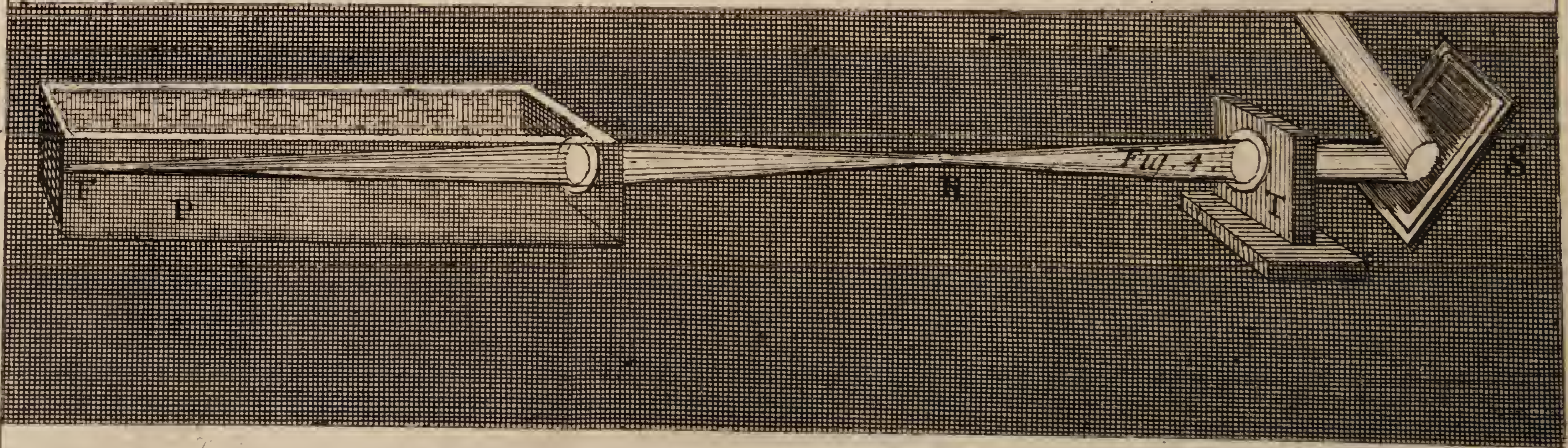


Fig. 4.

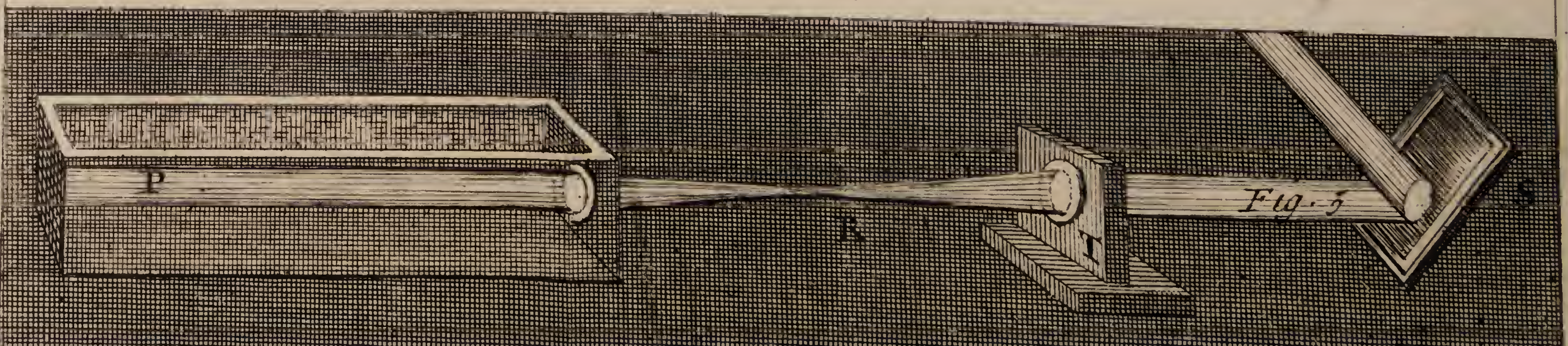


Fig. 5

If the radiant Point be brought nearer, the refracted Rays will diverge ; they *will diverge leſs than* 671
the incident Rays, if the radiant Point be more diſtant from the Surface than the Center *. * 667

But *if the radiant Point be between the Surface* 672
and the Center, the refracted Rays will be more divergent *. * 667

If the Rays are convergent, they become more convergent in every Caſe, which follows from the Re- 673
fraction being made fromwards the Perpendicular *; and which may alſo be deduc'd from N°.* 625
665.

Plate VII. *Fig.* 3.] *Let us* again *ſuppoſe the Rays* 674
to go out of the rarer Medium Z *into the denſer* X,
and that the Hollow or Concave of the ſpherical
Surface E S, *which ſeparates the Mediums, is towards*
the rarer Medium. If the Rays be *parallel*, as B O,
A *n*; B O which goes thro' the Center C of the
Surface E S, will not be refracted ; but A *n* is
refracted towards the Perpendicular C *p* thro'
n G *, and being continued towards Z, interſects * 624
B C O at *f*, which is alſo true in reſpect of the
Rays B O and A *n* *; thoſe Rays therefore *become* * 662
divergent, having their imaginary Focus F
in the rarer Medium.

Experiment 6. *Plate* VII. *Fig.* 4.] This Experiment differs from the firſt of this Chapter, only in this, that the Glaſs V has its Concavity towards the Air, the Trough P being in all other Reſpects the ſame ; in this Caſe the Rays of the cylindric Beam diverge in the Water.

675 *If Rays come from a radiant Point in* C B, *which is beyond* C (*Plate* VII. *Fig.* 3.) the Angle of Incidence A *n* C is diminiſh'd, and therefore alſo the Angle of Refraction G *n p* grows leſs ; that is, *the refracted Rays become more diverging*, and the

* 646 imaginary Focus *f* comes nearer to C *; till by the radiant Point coming nearer, at length it coincides with the imaginary Focus at C; for in
* 629 that Caſe the Rays undergo no Refraction *.

676 If the radiant Point comes nearer between C and O, the imaginary Focus is farther from O than the radiant Point, for it is always between that Point and C, by reaſon of the Angles of
* 624 Refraction being leſs than thoſe of Incidence *.

Experiment 7.] Things being as in the former Experiment; if you uſe the Board, with the Convex Lens in it, to form a radiant Point, the Experiments proving theſe Propoſitions may be eaſily made.

677 *If the Rays are converging, and the Point of Concourſe be in the denſer Mediums, near the Surface which ſeparates the Medium, the refracted Rays* will alſo *converge*, but *leſs than the incident Rays.*

678 If the imaginary Focus of the incident Rays recedes more and more from O, that is, *if they converge leſs, the refracted Rays will alſo converge leſs; until, by the receding of the imaginary Focus, the Rays become parallel.*

679 *If the imaginary Focus recedes yet farther, the refracted Rays become divergent.*

Experiment 8. *Plate* VII. *Fig.* 5.] Here the Board muſt be ſo plac'd in reſpect of the Trough, that the Rays may enter the Water converging; and the Phænomena above-mention'd may be ſeen, according as you remove the ſaid Board.

680 Rays which *from a denſer go into a rarer Medium, the concave Surface being towards this laſt,* are almoſt ſubject to the ſame Laws.

* 678 *Parallel Rays by Refraction become divergent* *.
* 626, 681 *If they proceed from a radiant Point, they become*
* 677 *more divergent* *.

And

Plate 7.

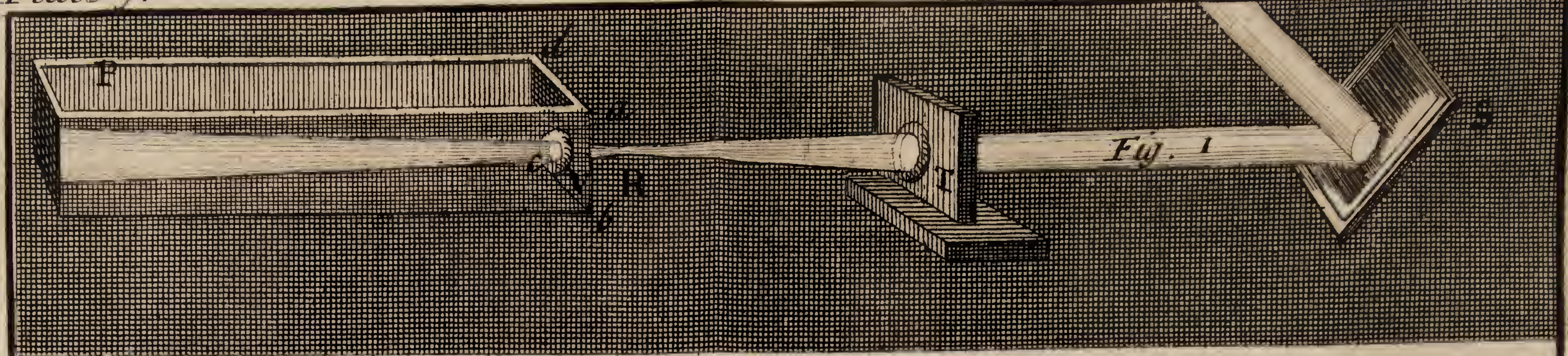


Fig. 1

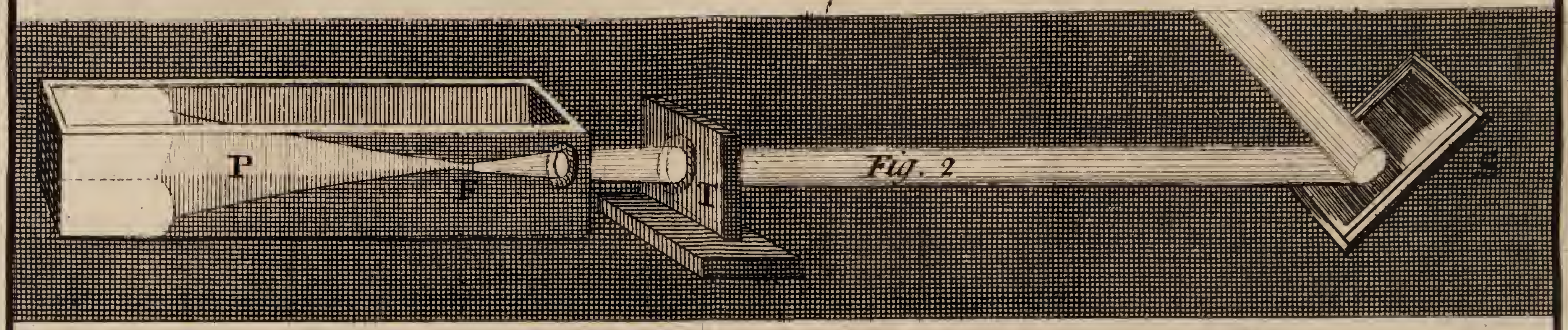


Fig. 2

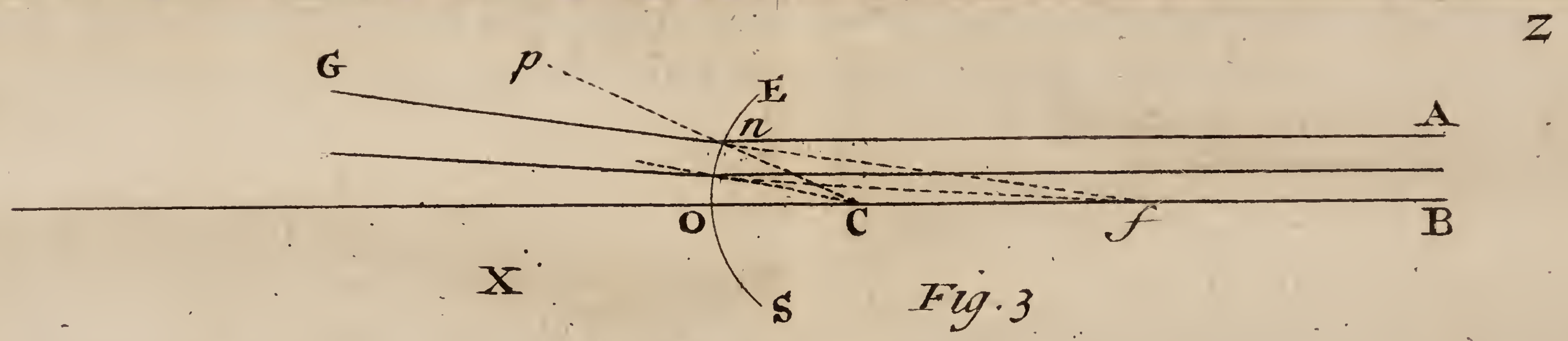

Z
G
p
E
n
A
O
C
f
B
X
S

Fig. 3

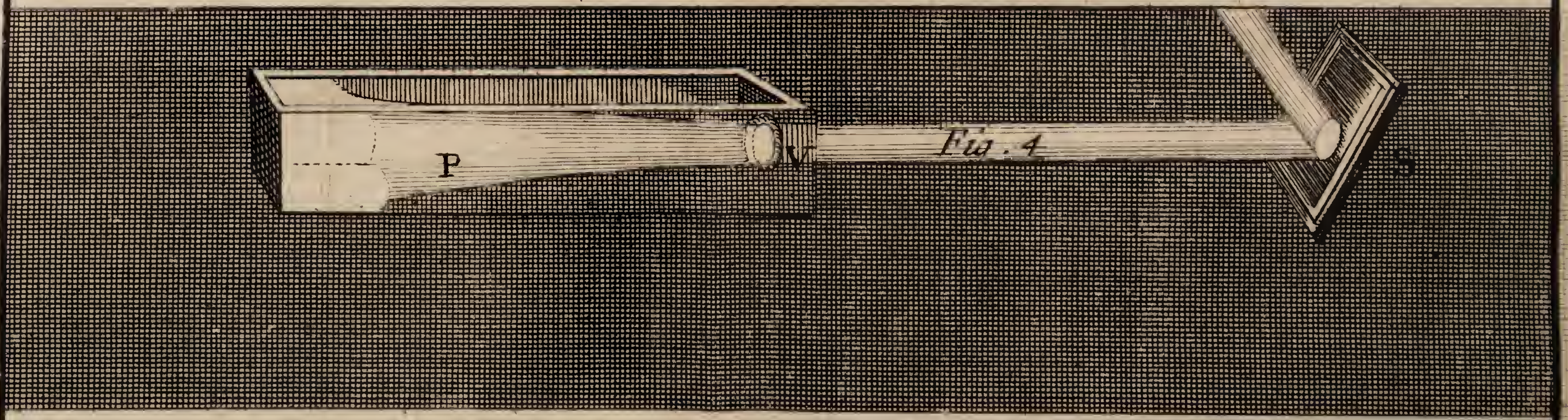


Fig. 4

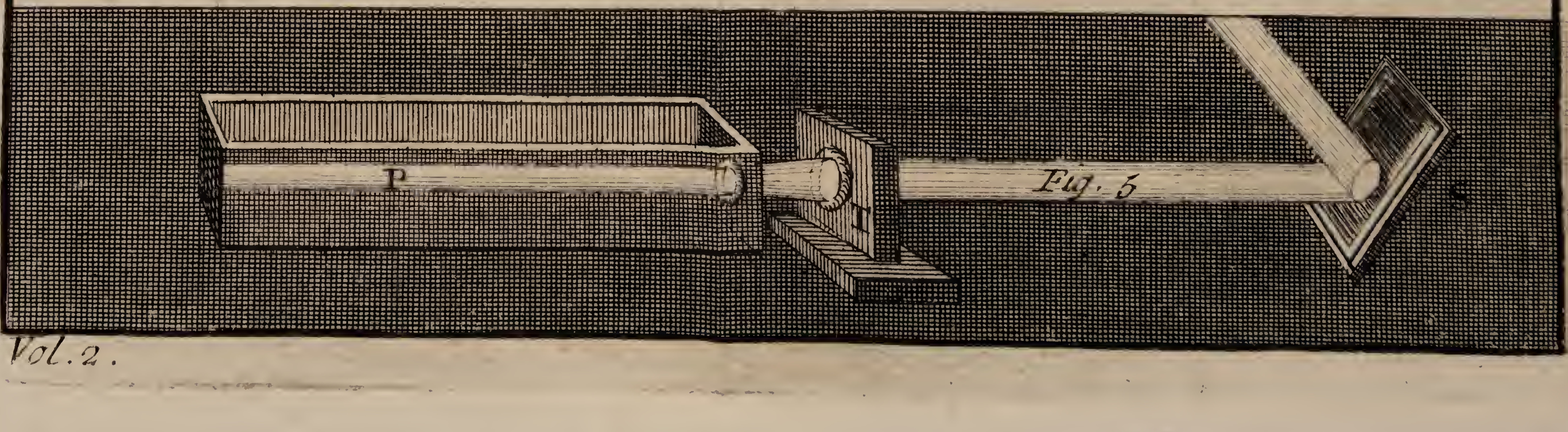


Fig. 5

And they diverge ſtill more and more, as the
radiant Point is brought nearer *. * 678

Converging Rays which tend to the Center of the 683
ſpherical Surface, undergo no Change *. * 629.

If they converge more or leſs, the imaginary Focus 684
of the incident Rays is always between the Center of
the Surface which ſeparates the Mediums and the Fo- 685
cus of the refracted Rays *, *which may recede* in in- * 675,
finitum, *ſo as to make the refracted Rays become* 676.
parallel *. * 674.

We have hitherto conſider'd ſuch Rays as are but little inclin'd to the Surface which ſeparates the Mediums; for we have mention'd ſuch incident Rays as diverge but little, and one of which is perpendicular to the Surface that ſeparates the Mediums. *The ſame Propoſitions hold* 687
good in oblique Rays, yet *in that Caſe all the Rays are inflected*, which does not happen ſo in direct ones; for the Ray which is perpendicular to the Surface is not inflected. Oblique Rays alſo undergo a greater Refraction, that is, *they are more inflected either to or from each other*, than direct ones, ſuppoſing the Circumſtances the ſame.

Plate VIII. *Fig.* 1.] Let Z be a rarer, and X a denſer Medium, ES the Surface ſeparating the Mediums, and having its Center at C; and the parallel Rays A*n*, B*m* will come together at F. The Rays that proceed from the radiant Point R will concur at *f*.

Plate VIII. *Fig.* 2.] If the Surface be turn'd ſo as to have its Concavity towards the rarer Medium, the parallel Rays A*n* and B*m* will have their imaginary Foci at *f*; but its Diſtance from the Surface ES, as alſo that of the above-mention'd Foci F and *f* in the *Figure* 1. is leſs, than if the Rays were direct.

688 *All the Points of a lucid Body are radiant Points, and have each their particular Focus,* which ſerves to explain the following Experiment, made to confirm what has been ſaid of the oblique Rays.

Experim.9. Plate VIII. *Fig.*3.] Take the Trough P mention'd in the firſt Experiment, and fill it with Water; let the Glaſs V be all cover'd, but a circular part in the middle of about half an Inch; have in the Trough a moveable white Plane T. If the Candle A be ſet at the Diſtance of 3 or 4 Foot from the Trough, let the Plane T be mov'd backward and forward in the Water, and when it is come to the Diſtance of the Foci of the Flame A, that Flame will appear exactly repreſented on that Plane; all the Foci forming a Picture. And this holds good whether the Rays from the Candle fall obliquely or directly upon the Glaſs V, only that when the Rays are oblique (the Diſtance of the Candle A remaining the ſame) the Diſtance of the Plane T from V muſt be leſs. In this caſe alſo the Candle and the Glaſs V will not be in the ſame right Line as the Repreſentation of it, as it happens when the Rays are direct, by which the Propoſition of N°. *686.* is confirm'd.

689 *The Candle is repreſented inverted,* becauſe the Rays, which proceed from different Points, interſect one another as they go thro' V, as may be plainly ſeen by looking at the firſt Figure. For which reaſon, if there are two Candles, as A and B, the Repreſentation of the laſt will be at *b*, and that of the firſt at *a*.

690 *All the Changes that happen in Light,* which we have taken Notice of in this Chapter, *are ſo much the more ſenſible, as the Surface ſeparating the Mediums is* more curve; that is, *a Part of a leſſer Sphere.*

CHAP.

CHAP. IX.

Concerning the Motion of Light through a more denſe Medium. Where we ſhall take Notice of the Properties of Lenſes.

THE Uſe of *Glaſſes* is common, they are more denſe than Air, and the Rays out of Air paſs thro' the Glaſs into Air again. According to the ſeveral Surfaces that terminate the Glaſs, Light undergoes different Changes as it moves in it; which to determine, the Glaſſes, or any Mediums encompaſs'd with a rarer Medium, and terminated with different Surfaces, muſt be examin'd. *If we conſider only plane and ſpherical Surfaces, there are ſix Sorts.* 691

1. The Medium may be plane or flat on both Sides. 2. Plane on the one Side and convex on the other. 3. Convex on both Sides. 4. Plane on one Side and concave on the other. 5. Concave on both Sides. 6. *Laſtly*, It may be terminated with a concave Surface on one Side, and a Convex one on the other.

DEFINITION I.

If Glaſs be made uſe of, and is not very thick, Glaſſes whoſe Figure is mention'd in the laſt five Caſes, are call'd *Lenſes of Glaſs.* 692

In the ſecond and third Caſe, a Lens is ſaid to be convex; and if we diſtinguiſh thoſe two Caſes, in the ſecond it is call'd *plano*-convex. And ſo in the fourth Caſe, it is ſaid to be *plano*-concave; tho' both this Caſe, and the fifth, is generally referr'd to concave Lenſes. But a *concavo*-convex Lens is referr'd to the concave or convex Lenſes, according as the one or the other Surface is predominant; and that is ſaid to be predominant which is moſt curve; that is, which is a Portion of a leſs Sphere.

DEFINITION II.

693 *In every Lens, or Medium, terminated in any manner above deſcribed, a right Line, which is perpendicular to the two Surfaces, is call'd the* Axis. When both Surfaces are ſpherical, the Axis goes thro' both their Centers; but if one of them be plane, it falls perpendicularly upon that, and goes thro' the Center of the other.

694 In the Paſſage of Light thro' a Medium, terminated by two plane Surfaces, *the Direction of the Rays is not changed;** which is the Caſe *in plane Glaſſes.* * 628

695 *It is the Property of all ſorts of convex Lenſes, that the Rays in their Paſſage thro' them are inflected towards one another; ſo much the more, as the Convexity is greater:* 696 *And of concave ones, that the Rays are deflected from one another, according as the Concavity is greater.* For the Direction of the Rays thro' a plane Glaſs is not changed;* but by inflecting one or both Surfaces, another Direction is given to the Rays: They are more inflected towards the Axis of the Lens by reaſon of the Convexity of the Surface of the Glaſs, and by making the Surface concave, they are deflected from the Axis; as is plain in every Caſe, by comparing the Inflexion in the plane Surface that is perpendicular to the Axis, with the Inflexion in the ſpherical Surface at any Diſtance from the Axis. And the Difference of their Inflexions, that is, the Change of the Direction of the Rays, increaſes as their Diſtance from the Axis does; and it is to be obſerv'd in every Direction of the Rays, as well in oblique Rays, as in direct: but *the Changes are greater in oblique Rays*, becauſe 697 the Angles of Incidence are greater. From which we deduce the following Properties of Lenſes. * 694

That *parallel Rays, by paſſing thro' a convex Lens, concur in a Focus.* 698

That *diverging Rays either diverge leſs, or run parallel, or laſtly, converge; in which caſe the radiant Point receding, the Focus comes nearer, and ſo on the contrary:* But this is the Caſe, when the radiant Point is farther diſtant from the Lens than the Focus of parallel Rays. 699

Laſtly, That *converging Rays converge more when the Light emerges out of the Lens.* 700

*The ſame things are obſervable in oblique Rays; concerning which it is to be noted, that the Diſtances of the Foci of the emerging Rays, are leſs than in the direct, and the other Changes more ſenſible.** 701

* 697

All theſe ſame Things may be deduced from examining the double Refraction in the Entrance and Emerſion of Light. And this double Refraction is viſible in every Caſe, by the following Experiments; by which the aforeſaid Properties of convex Lenſes are confirm'd.

Plate VIII. *Fig.* 4.] Take ſeveral Boxes like P, with Water in them, and thro' which Light is tranſmitted thro' the Glaſſes V and V, which are placed in the oppoſite Sides of the Box, and are diſtant from one another about one Inch. Theſe Glaſſes are thin; in the Box which repreſents a convex Lens, on each Side there is placed one, like that of the firſt Experiment of the former Chapter, which are ſo diſpoſed as to have their Convexities without the Box. When a *plano*-convex Lens is to be repreſented, on one Side there is a plane Glaſs. A *concavo*-convex Lens is repreſented by two ſpherical Glaſſes, that are Portions of different Spheres, and the Convexity of the Portion of the greater Sphere, muſt be turn'd towards the Inſide of the Box. 702

Whilſt the Light paſſes thro' theſe Boxes, the Changes of the Light are viſible to the Eye in its Entrance into, and Emerſion out of a denſer Medium, and by the Aſſiſtance of theſe, all things relating to convex Lenſes, are clearly demonſtrable.

Experiment 1.] *Ex. gr.* Let P be one of the forementioned Boxes, with the ſpherical Glaſſes V, V, their Convexities being placed outwards; let it be fill'd with Water; in a dark Room let a cylindric Beam of the Sun be horizontally reflected from the Looking-Glaſs S; let this Beam enter the Box; the parallel Rays of which it is form'd will be inflected towards one another, and will converge; at their Emerſion on the other Side, they will converge more, and concur in F. Experiments may be made of the incident Rays, which diverge or converge, by uſing the Board with the convex Lens, as in the Experiments of the former Chapter.

Every Point of a lucid Body, as was ſaid before, is a radiant Point,* and being placed at a due Diſtance from a convex Lens, every one has its Focus.* *688 *698

Experiment 2.] Let a lighted Candle be removed from a convex Lens beyond the Focus of parallel Rays; at the oppoſite Part of the Lens, upon a white Plane, by the Foci of the Points of the Flame, it will be repreſented; and this Repreſentation will be inverted, by reaſon of the Interſection of the Rays in their Paſſage thro' the Glaſs.

703 *Convex Lenſes are alſo burning Glaſſes,* becauſe they collect the Rays of * the Sun, which, upon the account of the immenſe Diſtance of the Sun, are eſteem'd as parallel. But Rays united in a Focus, (by reaſon that the Fire, that was before diſperſed, is now collected, and by rea- *698

Plate 8. front page 56.

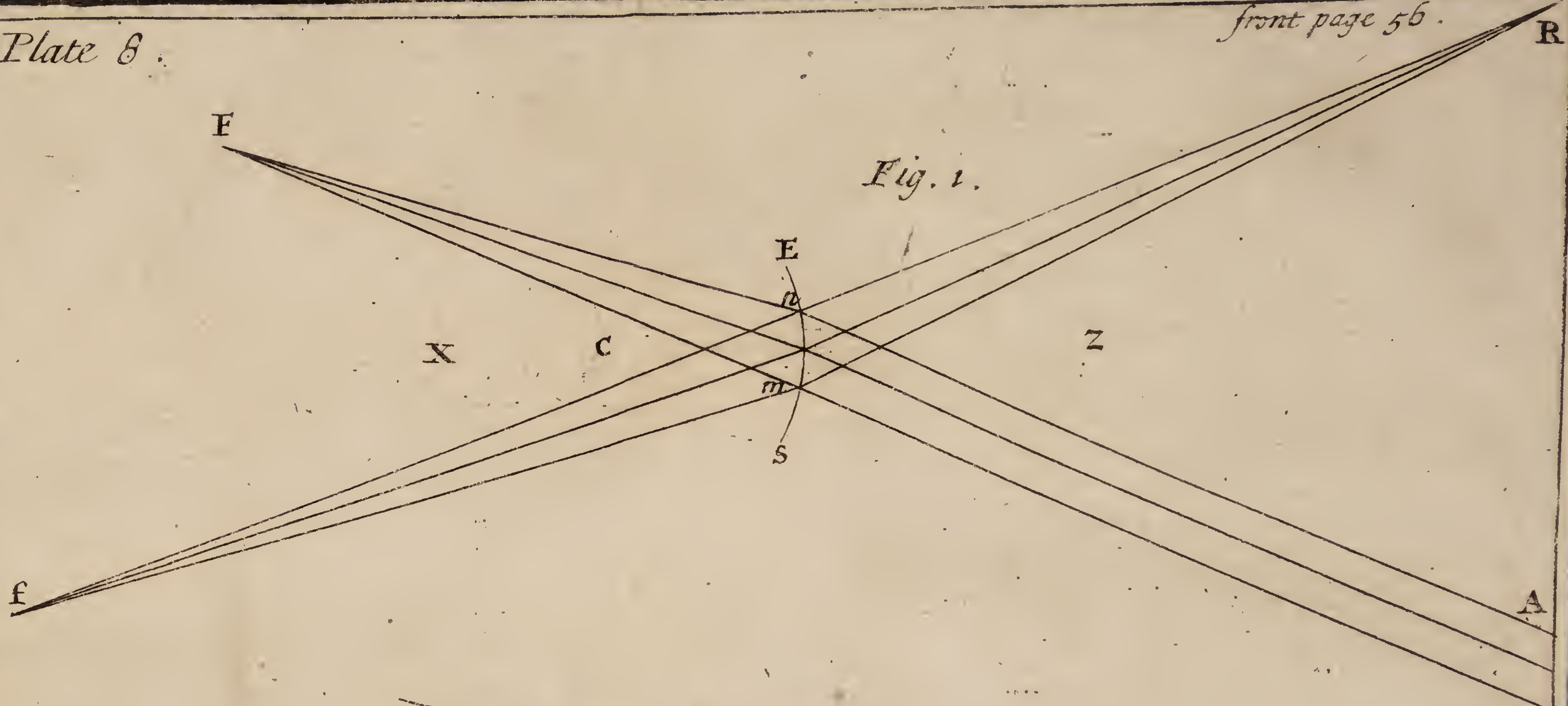

F
R
E
n
X
C
Z
m
S
f
A
B

Fig. 1.

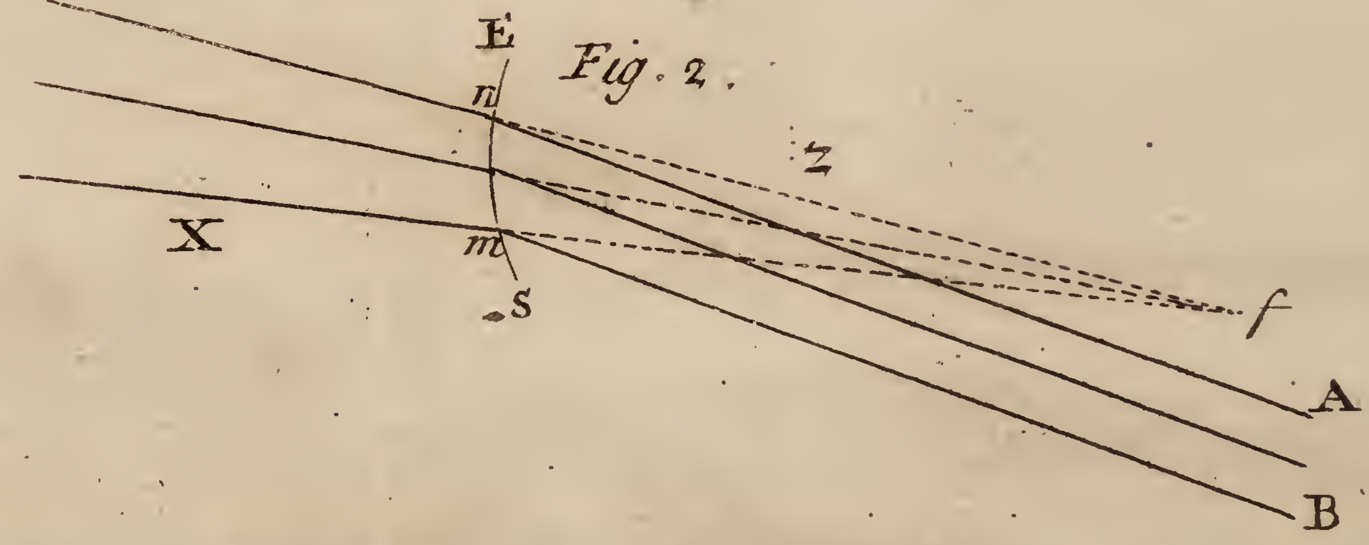


Fig. 2.

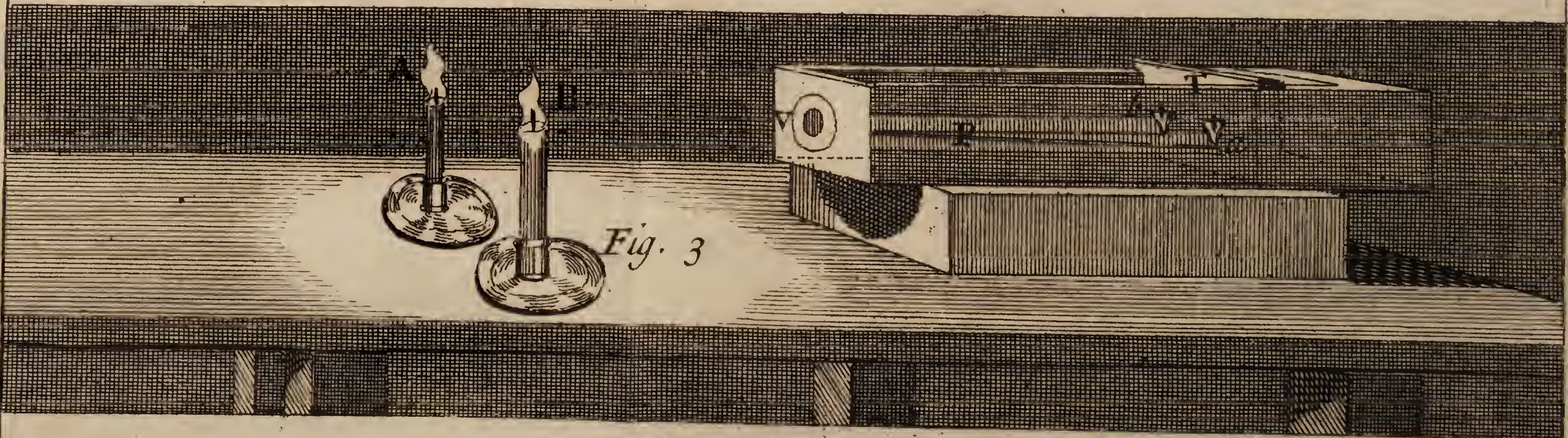


Fig. 3

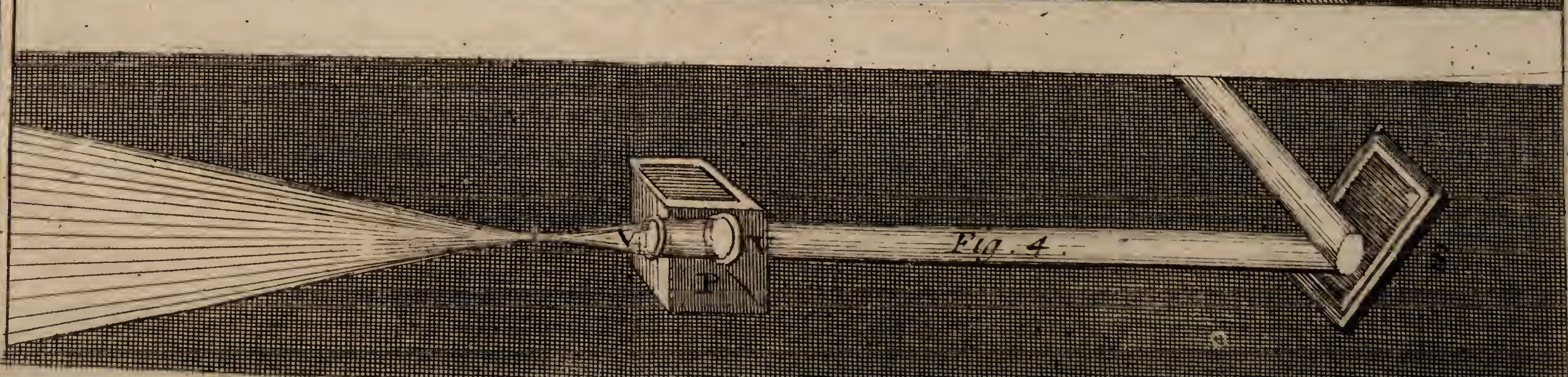


Fig. 4.

Vol. 2.

ſon of the Motion of the Fire, according to various Directions,) do burn vehemently.

Experiment 3.] Take a convex Lens of any Magnitude, let it be ſo expoſed to the Rays of the Sun, that the Axis of the Lens may be in the Direction of the Rays; if any combuſtible Body be placed in the Focus of the Sun's Rays, it will burn.

When by reaſon of the Magnitude of the Lens the Rays are not exactly enough collected, before they come to the Focus, they muſt be tranſmitted thro' another convex Lens that is leſs, by which they will be reduced into a ſmaller Compaſs, ſo as to burn more violently.

As for concave Lenſes, and their Properties, they may be eaſily deduced from * what has been ſaid. *696

Parallel Rays become diverging, by paſſing thro' a concave Lens. 704

Diverging Rays diverge the more. 705

Converging Rays either converge the leſs, or become parallel, or (as it happens in ſuch as converge leſs) *go out from the Lens diverging.* 706

All which things happen in oblique as well as direct Rays, but more ſenſibly in the firſt.* 707 *697

Plate IX. *Fig.* 1.] Boxes to repreſent the Effects of concave Lenſes, are made in the ſame manner as thoſe that repreſent the Effects of convex ones.* The Difference is only in the Poſition of the Glaſſes: In the firſt Box the Concavities of the two ſpherical Glaſſes V, V are outwards. In the ſecond, inſtead of one of thoſe Glaſſes, you have a plane Glaſs. In the third, you have two ſpherical Glaſſes, but Sections of different Spheres, the Section of the greater Sphere has its Convexity outwards, and the other its Convexity inwards. 708 *702

Experiment 4.] Parallel Rays of the Sun reflected horizontally in a dark Chamber by the Looking-Glaſs S, muſt be tranſmitted thro' the Box P, which is full of Water, and repreſents a Lens concave on both Sides: As they go into the Box they will begin to diverge, and as they go out they will diverge more.

The remaining Experiments relating to concave Lenſes are made in the ſame manner, as has been ſaid in reſpect of convex Lenſes.

CHAP. X.

Of Viſion; where we ſhall ſpeak of the Make of the Eye.

THE Properties and Laws of the Refraction of Light that we have explain'd, are of wonderful Uſe in repreſenting Objects to our Mind.

By theſe Laws, the Objects are beautifully painted in their proper Colours in the Bottom of the Eye; and this Picture, as I ſhall ſay hereafter,* is the Occaſion of the Ideas which are excited in our Minds concerning the Things that we ſee. *716

How this Picture is form'd in the Eye, cannot be explain'd, without examining a new Property of Light; namely, its Diviſibility, which is paſt our Comprehenſion.

DEFINITION.

709 *A Body that is not lucid, and intercepts the Light, is ſaid to be* opaque.

710 *Several* among all the opaque *Bodies,* when exactly poliſh'd (except perfectly black Bodies, if

there are any ſuch) have the Property of dividing Light; for they *reflect the Light, ſo that the Rays from every Point* being ſtruck back, are divided, and *recede every way,* ſo that *all the ſingle Points of the Body become as it were radiant Points,* from which Light goes every way.

711 Whence we deduce a Method of painting Objects upon a white Plane; for all the Points of the enlighten'd Body, from which the Rays come upon a convex Lens, have their Focus on the other Side of the Lens.* The Foci of diſtant Objects, tho' not exactly, are ſenſibly at the ſame Diſtance from the Lens; thoſe Objects may by theſe Foci be repreſented in the ſame Place; which Repreſentation is inverted, (by reaſon of the Interſection of the Rays as they go thro' the Glaſs,) and ſenſible in a dark Place, in which Light comes in no way but thro' the Lens, and only that Light by which the Objects are repreſented.

*699

This will do wherever the Lens is placed, and in reſpect of all the Points of Objects, enlighten'd by Rays of Light, from which right Lines without Interruption may be drawn to the Lens; in this manner the abovemention'd Diviſibility in Light may be proved, and the Aptneſs that Bodies that reflect Light have to divide it.

Experiment 1. *Plate* IX. *Fig.* 2.] Make an Hole in a dark Place, over-againſt ſeveral Objects that are at leaſt 50 Foot off or farther. Let the Hole be V, and let it have a convex Lens in it that collects parallel Rays at the Diſtance of about 4 or 5 Feet; if a white Plane be placed behind the Lens a little farther from it than that Diſtance, all the Objects abovemention'd will be painted upon it in very beautiful Colours. It is to be obſerv'd, that the Lens muſt be placed in a Poſition parallel to the Plane; and that by moving the Lens or the Plane, the Diſtance muſt be found at which the Objects are repreſented moſt exactly.

This Repreſentation of Objects has great Affinity with that by which the Objects that we ſee are repreſented in the Bottom of the Eye, as will appear from the Make of the Eye.

712 The Figure of the Eye, when taken out of the Head, is nearly ſpherical; only the Fore-part is ſomething more convex than the reſt.

The Section of the Eye is repreſented *Plate* IX. *Fig.* 3.

The Part A A, which is moſt convex, is tranſparent, and call'd the *Tunica Cornea.*

The whole Covering of the Eye, except the *Cornea,* is call'd the *Sclerotica,* B A A B.

That Part of the *Sclerotica* which is next to the *Cornea,* is call'd the *Adnata,* or *White of the Eye.*

Behind the *Cornea,* on the Inſide is a Coat call'd the *Uvea,* which has in its Middle an Hole *p p,* call'd the *Pupil.*

The Uvea is made up of concentric circular Fibres, interſected at right Angles by ſtrait Fibres. If the firſt are ſwell'd the laſt are relax'd, and the Pupil is leſſened or contracted; and a contrary Motion of the Fibres, increaſes or widens it.

In the middle of the Eye, but nearer the Fore-part, there is a tranſparent ſoft Body C C, like a convex Lens, whoſe Hind-part is more convex than the Fore-part. It is call'd the *Cryſtalline Humour.* Its Axis coincides with the Axis of the Eye that goes thro' the Centers of the Pupil and the whole Eye.

This cryſtalline Humour is ſuſtain'd by ſmall Fibres or Threads, which are fix'd to all the Points of its Circumference, and likewiſe to the

Inſide of the Eye: They are inflected in the Form of an Arc, and every one of them is a Muſcle; they are call'd the *Ligamenta Ciliaria*, and two of them are repreſented by *l* C, *l* C. They all cohere to one another, and together with the Cryſtalline, make a Separation in the Eye, and divide it into two Cavities, one forwards *p p*, and the other backwards S S.

The Cavity that is forwards is fill'd with a Liquor like Water, call'd the *Aqueous Humour.*

The hind Cavity is fill'd with a tranſparent Humour, nearly of the ſame Denſity as the Aqueous Humour, but not ſo fluid, call'd the *Vitreous Humour.*

The hind Surface of the Eye within, is lined with a Coat call'd the *Choroides*, which is again cover'd with a thin Membrane call'd the *Retina.*

At the back Part of the Bulb of the Eye, a little on one ſide, is the Optic Nerve N N ſo join'd to the Eye, that the Eye itſelf is, as it were, an Expanſion of the Optic Nerve; for the expanded Coats of the Nerve form the Choroides and Sclerotica, and the Fibres, which make up the Retina, concurring, make the Marrow of the Nerve.

The Eye is moved in the Head by ſeveral Muſcles inſerted in the Sclerotica; but we ſhall not treat of them here: as we only conſider the Eye with reſpect to the Motion of Light, we purpoſely forbear to take notice of any thing elſe.

713 *Rays that proceed from any Point, and enter the Eye thro' the Pupil*, go out of a rarer into a denſer Medium thro' a ſpherical Surface; and therefore *if that Point be at a due Diſtance from the Eye*, the Rays *after Refraction will converge*;* in the ſame manner as in the Experiment of N° *663*. (*Plate* VI. *Fig.* 4.) in which the Glaſs V repreſents the tranſparent Cornea of the Eye, whilſt the Water in

*661

in the Trough is inſtead of the aqueous Humour; and therefore *ſuppoſing only the Cornea and*
714 *the aqueous Humour, there will be in the Eye an inverted Picture of the Objects.**
*710, 711

Experiment 2. *Plate* IX. *Fig.* 4.] Let P be the Trough abovemention'd full of Water, and ſet in a dark Place, which has an Hole about half an Inch wide, ſo diſpoſed towards enlighten'd Objects at a certain Diſtance, that one may ſee them thro' the Hole; let the Glaſs V of the Trough be applied to this Hole, and upon the white Plane **T** you will have an inverted Picture of the Objects: By moving the Plane backwards and forwards, you will find the Place where the Picture is moſt diſtinct.

If the abovemention'd Picture, which we have imitated in this Experiment, was to be made in the Eye, it would be at too great a Diſtance from the Cornea, and beyond the Bottom of the Eye; and therefore this Diſtance is diminiſh'd
715 *by help of the Cryſtalline Humour,* which is denſer, but encompaſs'd with rarer Mediums; for the Rays converging in the aqueous Humour, paſs thro' the cryſtalline into the vitreous Humour; that is, out of a rare Medium thro' a denſer, (which is terminated by two ſpherical convex Surfaces) into a rare Medium again; by which
700 Motion the Rays converge ſtill more; and therefore they concur ſooner, and *the Picture abovementioned falls within the Eye.*

716 *The Objects which,* as we have explain'd, *are repreſented in the Bottom of the Eye, are painted upon the Retina; and by the Motion of Light the ſmall Fibres of which the Retina is made up, are agitated; by which Agitation, the Ideas of the Objects painted in the Eye, are excited in the Mind.* The Connexion between the Ideas and the Motions by which

they are excited, is unknown to us,* as we ſaid before: In determining the Cauſes of Senſations, we can go no farther than the Agitation of the Nerves. * 502

717 *The more exact the Picture above deſcribed is, the more diſtinct will the Objects appear.* 718 *When the Rays coming from the ſame Point are not exactly united upon the Retina,* its Picture is not a Point, but a Spot, which is confounded with the Pictures of the neighbouring Points; in which caſe the *Viſion is confuſed.*

719 But when, *according to the different Diſtance of the radiant Point,* its Focus is brought nearer, or removed farther off,* *it is neceſſary that there ſhould be a Change in the Eye, leſt* the Place in which the Picture is exact, ſhould fall ſhort of, or beyond the Retina, and ſo *the Viſion ſhould be confuſed.* * 663

But it is very difficult to determine what this Change is, and Philoſophers are divided in their Opinions about it: I ſhall only obſerve in general, that *it is not very probable that the Figure of the whole Eye is changed, in order to put back or bring forward the Retina*; and therefore we muſt expect to find this Change within the Eye. 720

For if the Figure of the Eye was changed, as this Change muſt be equally neceſſary in all Animals, the Eyes of all Animals would undergo the ſame Changes; for the ſame natural Effects cannot have different Cauſes. Now in the Whale the Sclerotica is too hard to be ſubject to any Alteration of Figure. Beſides, if there was ſuch a Change in the whole Eye, it would ariſe from the external Preſſure of the Muſcles, which would be different in different Poſitions of the Eye, and only regular in one Situation of it.

If now we examine the Eye within, it will appear neceſſary that there ſhould be a Change in the Cryſtalline; which by changing its Place

or Figure in the Eye, will produce the deſired Effect; for the Rays that fall upon the Retina before they are united, will be made to unite juſt upon the Retina, if the Cryſtalline becomes
* 695 more convex,* or if (its Figure remaining the ſame) it be brought forwards towards the Cornea.

721 That *the Poſition of the Cryſtalline Humour is* eaſily *changed,* and that *it is brought nearer to, or farther from the Retina,* its Axis remaining the ſame, is plain, becauſe the ciliary Ligaments are muſcular: When theſe Muſcles are ſwell'd, and become ſhorter, the Hollow which their Inflection makes at C *l*, C *l*, becomes leſs; by which means the vitreous Humour is compreſs'd, and therefore it preſſes upon the Cryſtalline, and puſhes it forwards farther from the Retina; which is neceſſary when we look at near Ob-
* 663, jects.*

699 From an Experiment that we ſhall hereafter mention, it has been demonſtrated, that there is another Change in the Eye that acts contrary to this; and we ſhall ſhew what is the Occaſion of it. The ſecond Change is alſo to be referr'd to the Cryſtalline; which (when it is drawn by the ciliary Ligaments, to make it recede from the Bottom of the Eye) becomes alſo flatter, and therefore it muſt recede farther than if its Figure was unchangeable; that is, the Change becomes more ſenſible; which we ſhall
* 730 ſhew to be of Uſe.*

These Changes in the Eye have their Limits, for which Reaſon alſo *Objects appear only diſtinct*
724 *within certain Limits, which are at different Diſtances*
725 *according to the Difference of People's Eyes; and very often in the ſame Man, both Eyes have not the ſame Limits*; which is almoſt of the ſame uſe, as if the Limits of both Eyes were more diſtinct from

one another: For one may ſee an Object diſtinctly enough with only one Eye. In ſome Perſons alſo the neareſt Limit of one Eye is farther off than the fartheſt of the other: in which caſe near Objects and diſtant Objects are ſeen diſtinctly, but the intermediate ones appear confuſed.

The Picture in the Bottom of the Eye, as has been ſaid,* is inverted; whence a Queſtion ariſes, why we ſee Objects erect? To which we anſwer by asking another Queſtion; Whether it is more eaſy to conceive the Connexion between an Idea in the Mind and an erect Figure than an inverted one? We confeſs, that we have no Notion of that Connexion in either caſe: but Experience teaches us, that there is a Connexion between an inverted Picture in the Eye, and the Idea of an erect Object; and further than this we do not know. 726

*714

If we look at the ſame Object with both Eyes, it will appear ſingle; but this happens only when the Object is painted in correſpondent Points of each Retina; which probably happens from the meeting of the Optic Nerves. For it is obſerv'd in all Animals, which ſee the ſame Object with both Eyes, that the Optic Nerves meet and ſeparate again before they go to the Brain; but in Animals which ſee different Objects with each Eye, the Optic Nerves go ſeparately from the Eyes to the Brain. 727

Only one Point at a Time can be ſeen diſtinctly; namely, that which is repreſented in the Axis of the Eye; if we look at one Point with both Eyes, we muſt ſo direct the Eyes, that their Axes continued ſhall meet in that Point; which happens when we have our Eyes intent upon any Point. 728

By this Direction of the Axes we judge of the Diſtance of Objects; for the Situation of the Eyes alter according as the Axes make a different Angle, which Angle depends upon the Diſtance of the Object: Whence it happens, that without perceiving when we do it, by Uſe we get a Habit of judging of the Diſtance of Objects *by the Direction of the Axes*; which is ſenſible to us, becauſe it depends upon the Motion of the Eye, that we feel. Therefore we may ſee the Uſe of having two Eyes placed at a certain Diſtance from one another; *as long as this Diſtance of the Eyes bears a ſenſible Proportion to the Diſtance of the Objects, we can judge of it pretty certainly.*

730 *We can alſo judge of leſſer Diſtances with one Eye alone*; becauſe in the Variation of a ſmall Diſtance, the Change in the Eye is ſenſible.* *721, 723

731 *In great Diſtances*, if we look at known Objects, *we judge from the apparent Magnitude, and the Colour.*

732 *It is impoſſible to judge of very great Diſtances, except the ſame Object be ſeen from different Places.*

733 *The apparent Magnitude of an Object, depends* upon the Bigneſs of the Picture in the Bottom of the Eye, which Picture depends *upon the Angle under which an Object is ſeen*, that is, the Angle which is form'd by Lines drawn from the Extremities of the Object to the Eye.

734 *This* apparent *Magnitude* is to be diſtinguiſh'd from that Magnitude *which our Mind attributes to the Object that we ſee*, which laſt is founded upon the Judgment, whoſe Foundation is not in the Appearance alone. Every body knows, that the Object appears the leſs according as it is more diſtant; whence it happens, that *according to the greater Diſtance of the Object*, if it be known, the apparent Magnitude of the Object *is increaſed* in

Plate 5.

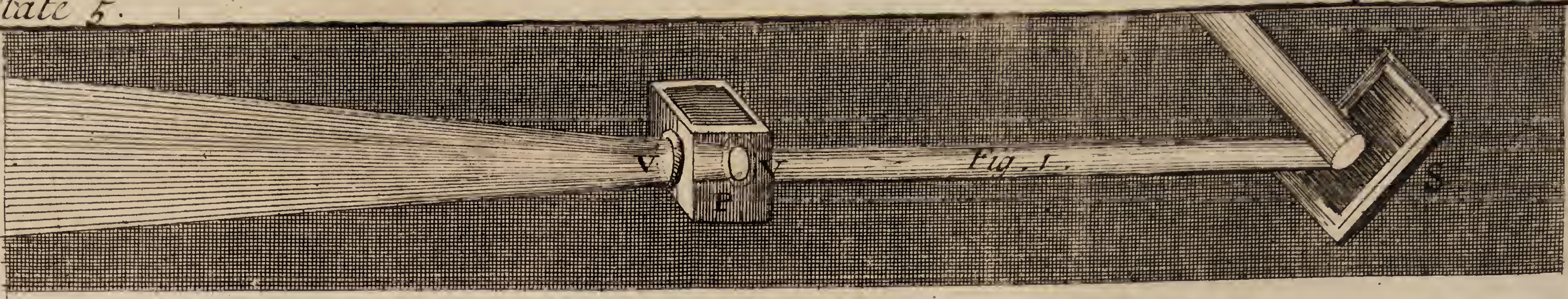


Fig. 1.

Fig. 2

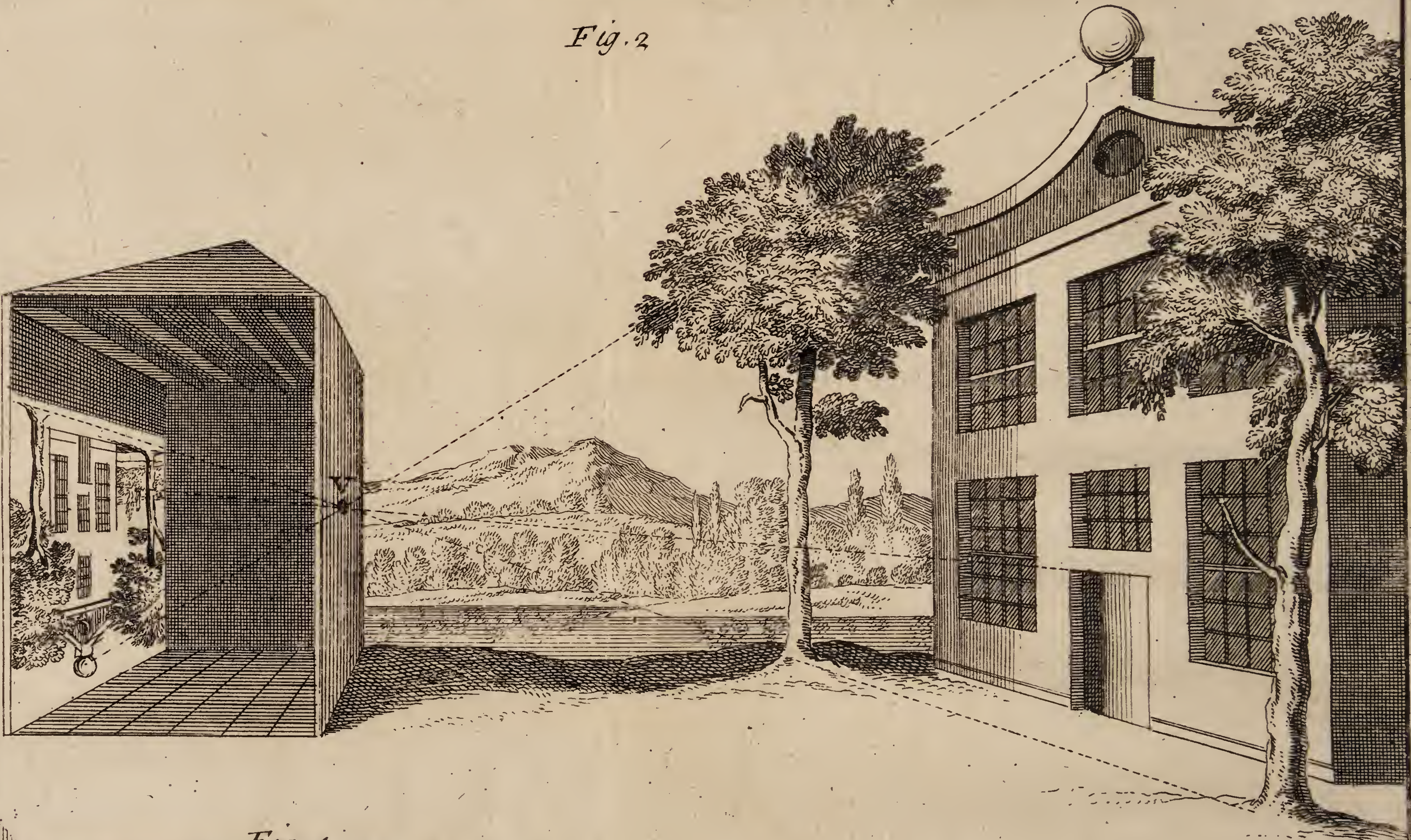


Fig. 4.

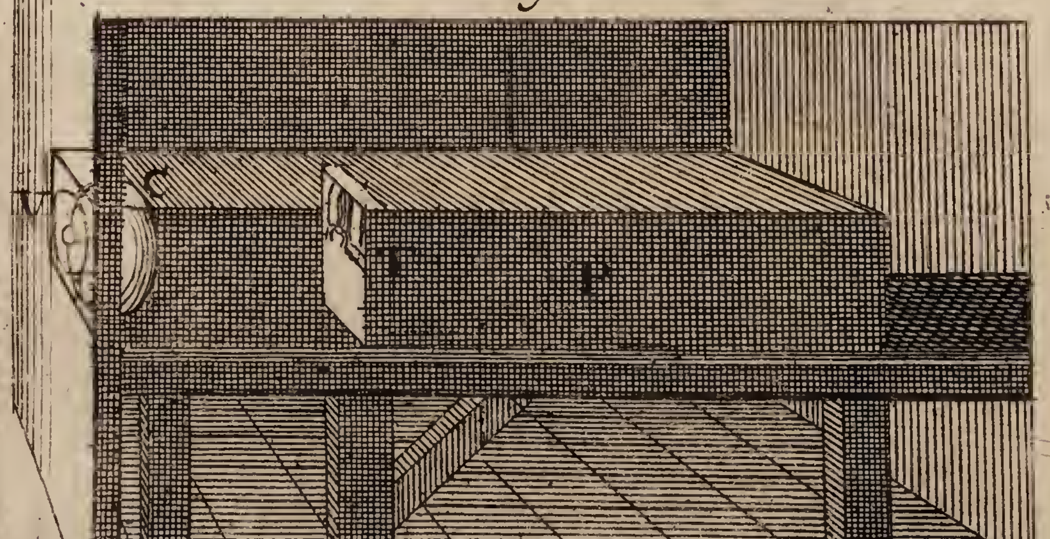


Fig. 3.

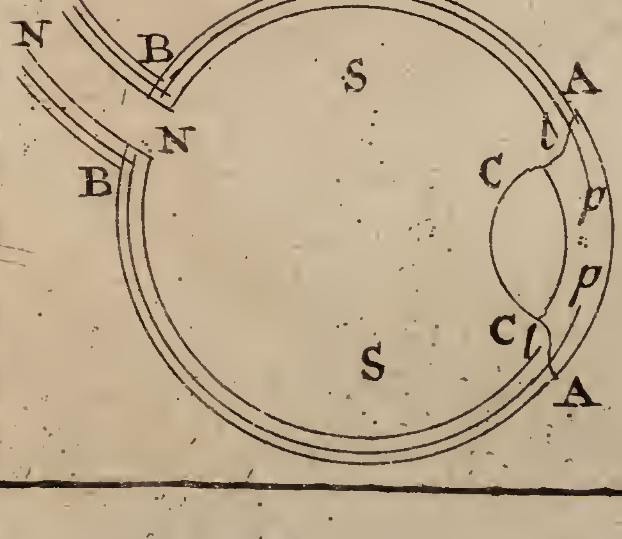
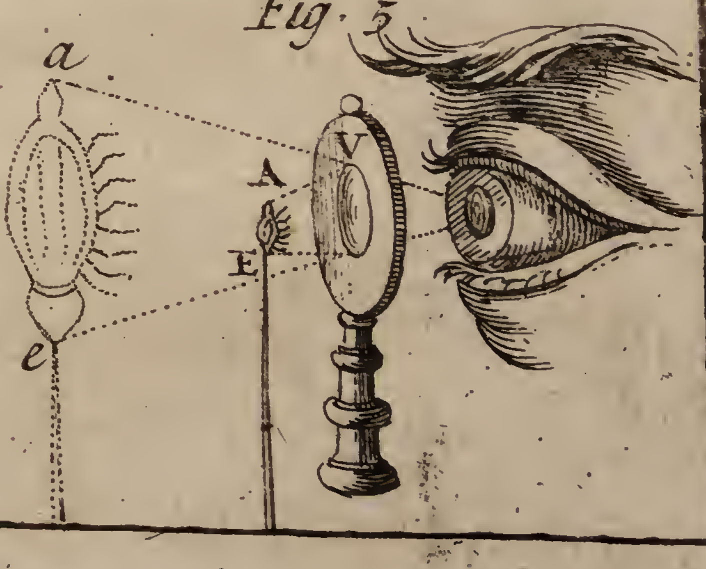

N
B
N
B
S
A
C
l
p
p
C
l
S
A

Fig. 5



in the Judgment that our Mind makes of it, which we do without any Attention to it. Therefore the ſame Object at the ſame Diſtance appears of a different Magnitude, if we judge differently of the Diſtance.

We have a remarkable Example of this in reſpect of the Sun and Moon, which appear greater when near the Horizon, than at a greater Height; tho', as is known to Aſtronomers, the Picture of the Sun in the Bottom of the Eye is the ſame in both Caſes, and that of the Moon is leſs when it appears near the Horizon; we cannot judge of the Diſtance in either Caſe,* but it appears greater near the Horizon by reaſon of the Interpoſition of the Fields and part of the Heavens. If we ſee the Bodies abovemention'd thro' a Tube, this apparent Diſtance vaniſhes, as alſo the Magnitude which is deduced from it. From our Childhood upwards, and ſo continually, we join the Idea of Diſtance with the Increaſe of apparent Magnitude, (which is neceſſary for making a true Judgment concerning Magnitude) whereby the Ideas are ſo cloſely join'd, that they cannot be ſeparated, not even in thoſe caſes, in which we know that they lead us into Error. Logicians teach us, how many Errors are to be attributed to Ideas ſo join'd. 735

* 732

CHAP. XI.

Of Viſion thro' Glaſſes, and how to correct ſome Defects of the Eyes.

AN Object is viſible, becauſe all its Points are as it were radiant Points;* therefore *a Point appears in that Place from whence diverging Rays are emitted.* 736

* 713, 714, 715

737 *If Rays inflected any how enter the Eye diverging, the viſible Point will be in the imaginary Focus of the Rays;* for the Rays enter the Eye exactly in the ſame manner that Rays would do that came directly from that Focus; and to have them unite upon the Retina, the ſame Situation of the Cryſtalline is requiſite; ſo that in reſpect to a Spectator, it is no matter whether thoſe Rays after Refraction, or theſe directly enter the Eye; and there will be the ſame Motion in the Eye, when it fits itſelf for diſtinct Viſion.* *719, 730

738 *A Point appears the more enlightened, the greater Number of Rays coming from it enter the Eye.*

739 *When Objects are ſeen thro' a plane Glaſs terminated with parallel Surfaces, they appear to be nearer than when ſeen with the naked Eye.* Let A (*Plate* X. *Fig.* 1.) be a viſible Point; the Rays going from it and entring the Eye, are between A *b* and A *b*; theſe being refracted in the Glaſs V V, move along *b c*, *b c*, and go out thro' *c d*, *c d*, which are parallel to the Lines A *b*, A *b*:* now becauſe *b c*, *b c* are refracted towards the Perpendicular,* *c d*, *c d* fall between *b* A and *b* A; that is, they interſect at *a*, which is nearer than A; therefore the imaginary Focus of the Rays which enter the Eye is at *a*, in which the Point A appears to be.* *628 *624 *737

740 *That Point* alſo *appears to be more enlightened, when ſeen thro' the Glaſs abovementioned.* For all the Rays between A *b* and A *b* enter the Pupil between *d* and *d*; but as the Lines A *b*, A *b* are parallel to the Lines *c d*, *c d*, and theſe are between thoſe, A *b* and A *b* being continued would fall beyond *d* and *d*; therefore if the Glaſs was taken away, the Rays which now enter the Pupil would take up a greater Space, and therefore would not all enter the Eye.

Plate X. *Fig.* 2.] *The apparent Magnitude of an Object is increaſed by the Interpoſition of a plane Glaſs*; the Object A E is ſeen by the naked Eye under the Angle A *d* E; but if you uſe the Glaſs V V, by reaſon of the Refraction thro' A *b c d* and E *b c d* it will be ſeen under the Angle *c d c*, which is greater than the laſt. 741 *But yet the Object is not greater in Proportion to the increaſed apparent Magnitude*;* for it appears to be at a leſs Diſtance.* 742

[*] 734

[*] 739

The Increaſe of apparent Magnitude is ſo much the greater, as is the Difference of the Angles A *d* E and *c d c*; whoſe Difference *increaſes* as the Interſections of the Lines A *d* with *b c* and E *d* with *b c* come nearer to the Points *b* and *b*; which obtains *as the Object is brought* nearer to the Glaſs; and therefore it is the greateſt of all when the Object touches the Glaſs; which ſhews that Objects, even in the Glaſs itſelf, muſt appear magnified. 743

And in general, *the Eye being placed in a rarer Medium, the Object that is ſeen in a denſer Medium appears bigger, and is alſo brought nearer by the Refraction.** This is every Day confirmed by Experience, when we look at Objects in the Water. 744

[*] 659

Let there be *a Point* A *ſeen thro' a convex Lens* V V, (*Plate* X. *Fig.* 3.) and the Rays A *b*, A *b*, at *c d*, *c d* will go out more diverging, as if they came from *a*;* therefore that Point *appears to be at a greater Diſtance.** 745 *It appears alſo more enlightened*; for the Rays come nearer to each other as they go thro' the Glaſs,* and are alſo reduced into a leſs Space, wherefore a greater Number of them muſt enter the Pupil. 746

[*] 699

[*] 737

[*] 695

The apparent Magnitude of an Object is alſo increaſed; that is, the *Object ſeen thro' a convex Glaſs* is ſeen under a greater Angle, which ap- 747

pears from a Sight of the Figure: the Object
A E ſeen with the naked Eye, is ſeen under the
Angle A *d* E, (*Plate* X. *Fig.* 4, and 5.) but now
it is ſeen under the Angle *c d c*, which is greater;
(in *Fig.* 4.) the Rays A *b*, E *b*, which are convergent,
converge more as they go out of the
* 700 Lens;* or diverging (as in *Fig.* 5.) they come
* 699 to the Eye converging.* Therefore the Object
appears magnified, both from the Appearance of
* 745 it being farther,* and its Magnitude being increaſed;*
* 734 and therefore *the Magnitude that we*
748 *attribute to an Object, does not follow the ſame Proportion*
as the apparent Magnitude; for which reaſon
we ſhall not delay Time in Demonſtrations
about it: But we ſhall obſerve in general,

749 That *the Angle, under which an Object is ſeen thro' a convex Glaſs, diminiſhes as the Eye recedes from the Glaſs; whilſt the Object is not more diſtant from the Glaſs than the Point in which parallel Rays are collected: But if the Object is farther off, the apparent Magnitude is increaſed as the Eye recedes.*

750 After the ſame manner, *if the Eye be between the Glaſs and the Focus of parallel Rays, the Angle abovementioned is diminiſhed as the Object is farther removed; the Eye being placed at a greater Diſtance, the ſame Angle is increaſed as the Object is farther removed*; in which laſt Caſe the Object may be
ſo far removed, as not to be viſible beyond the
* 754 Glaſs, as will be ſaid anon.*

Alſo in thoſe Caſes in which Objects are viſible, they do not always appear diſtinctly.

751 For, *that a Point may appear diſtinct, it is required*
that the Rays that proceed from a Point ſhould enter
* 736 *the Eye diverging,** *and that the imaginary Focus of*
* 737 *thoſe Rays, in reſpect of the Spectator, ſhould be with-*
724 *in the Limits of diſtinct Viſion.**

752 If the Object be removed beyond the Focus of parallel Rays, the Rays flowing from a Point

of the Object, enter the Eye converging;* which Caſe is impoſſible to the naked Eye: in this the Viſion is always confuſed, and the Eye diſpoſes itſelf ſo as to have the Viſion the leaſt confuſed that may be; from this Diſpoſition we judge of the Diſtance, as we do in every Caſe in which we judge of it with only one Eye.* *699 *730

753 But this Diſtance does not always appear to be the ſame; whence may be deduced what is ſaid of the Change of the Figure of the Cryſtalline.* For if, ſuppoſing the Cryſtalline moveable, its Figure be unchangeable, in every Situation of the Object and the Eye, in which the Rays, coming converging from a Point, enter the Eye, there will be the leaſt Confuſion, if the Cryſtalline comes back towards the Retina as far as may be; ſo that in every Caſe there would be the ſame Diſpoſition of the Eye, and the ſame Judgment concerning the Diſtance; which, as has been ſaid, is contrary to Experience: but if it becomes flatter as it recedes from the Retina, there will be Changes in the Eye, which agree with the ſeveral Judgments made of the Diſtance in different Situations of the Object and the Eye. *722

754 *If in the laſt Caſe, in which Rays coming from a Point converge, the Eye be ſo removed, that the Rays unite before they come to the Eye,* in all the Points in which the Rays concur, there will be radiant Points; which are the Foci of all the Points of the Object, by which the Object is repreſented inverted upon a white Plane;* and which are viſible Points in reſpect of the Eye, to which the Rays can come after their Interſection.* In that caſe *the Object appears inverted*, becauſe we don't ſee the Object itſelf, but its Repreſentation behind the Glaſs, which we have ſaid to be inverted.* *711 *736 *711

755 We have ſaid that the Caſe is impoſſible to the naked Eye, in which the Rays coming from a Point enter the Eye converging; and therefore ſuch Viſion is always confuſed, becauſe the Conſtruction of the Eye cannot adapt itſelf to an impoſſible Caſe: Yet ſometimes, but rarely, even in that Caſe, the Objects are ſeen diſtinctly; which, as it is occaſioned by ſuch a Defect of the Eye as takes away all diſtinct Viſion from the naked Eye, I did not think proper to take notice of ſuch Exceptions of the general Rule.

756 *The Fault of the Eyes of a great many Old Men* is, that they can ſee none but diſtant Objects diſtinctly, thoſe that are near appearing confuſed to them; which Defect *is corrected by the Interpoſition of a convex Lens.* The Rays which flow from a Point which is near, concur beyond the Retina; paſſing thro' a convex Glaſs, they will diverge leſs as they enter the Eye, and ſo concur ſooner in the Eye; that is, come to the Eye as if they flow'd from a remote Point, ſuch as is ſeen diſtinctly by an old Man.

757 *Thro' a concave Lens Objects appear to be nearer, leſs enlighten'd, and leſs.*

Plate X. *Fig.* 6.] The Rays A *b*, A *b*, and all that are between, going thro' a concave Lens
* 705 become more diverging,* and enter the Eye as if they came from a Point *a*, which is leſs di-
* 652 ſtant,* where the Point A appears to be.*
* 737

By making the Rays to diverge more, they are carried farther aſunder; and therefore fewer of them enter the Eye, which diminiſhes the Il-
* 738 lumination of the Point ſeen.*

Plate X. *Fig.* 7.] The apparent Magnitude is alſo diminiſh'd, becauſe the Rays A *b*, E *b*, by which we ſee the Extremities of the Object
* 706 come to the Eye leſs converging,* and therefore the Angle *c d c* under which the Object is ſeen

Fig. 1.

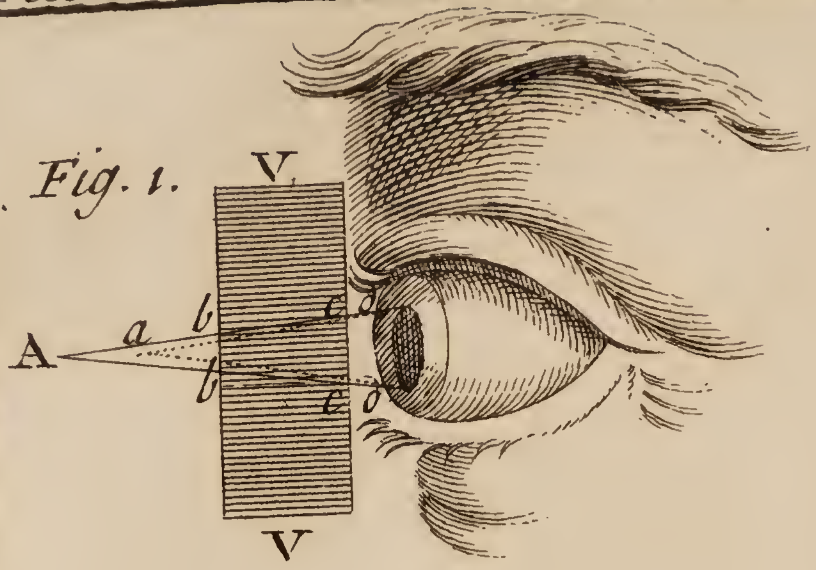

V
A
a
b
c
d
b
c
d
V

Fig. 2

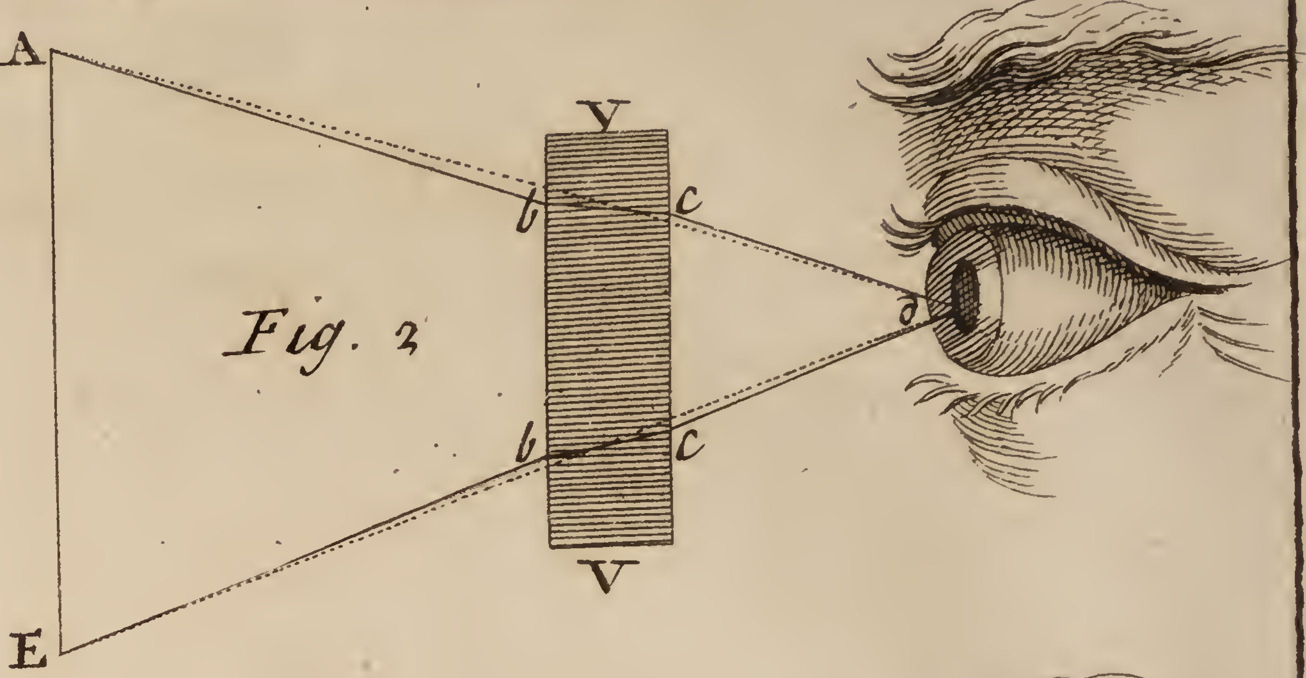


Fig. 6.

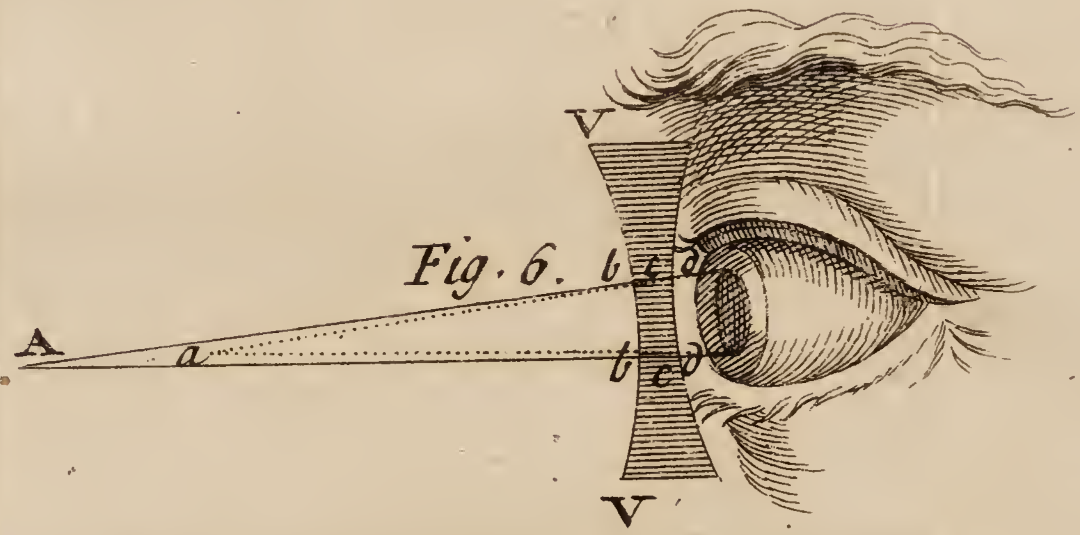

V
b
c
d
A
a
b
c
d
V

Fig. 3

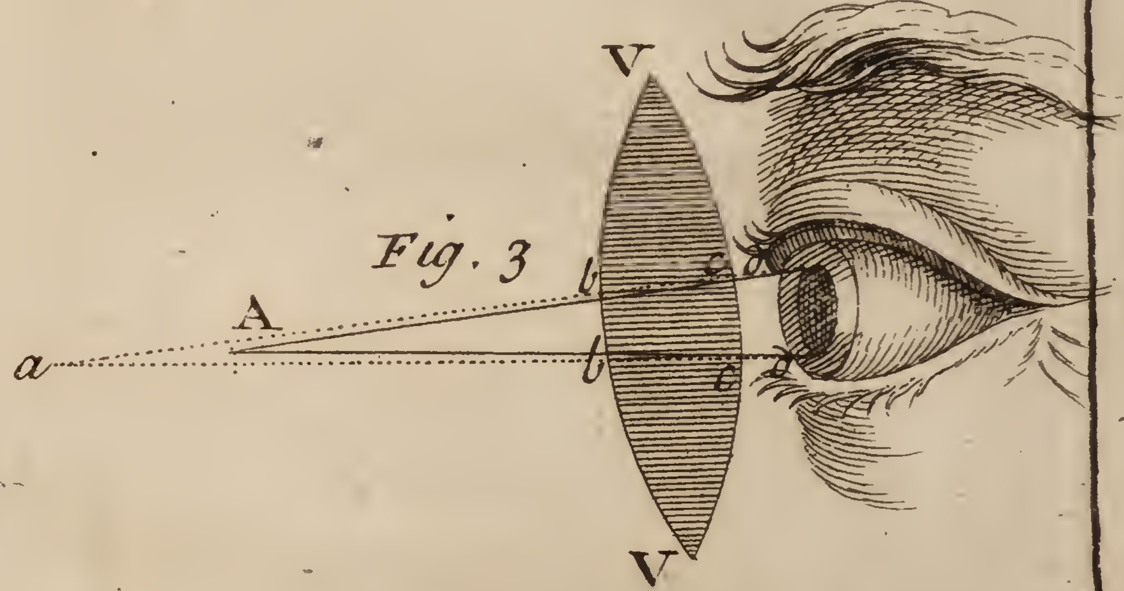

V
b
c
d
A
a
b
c
d
V

Fig. 4.

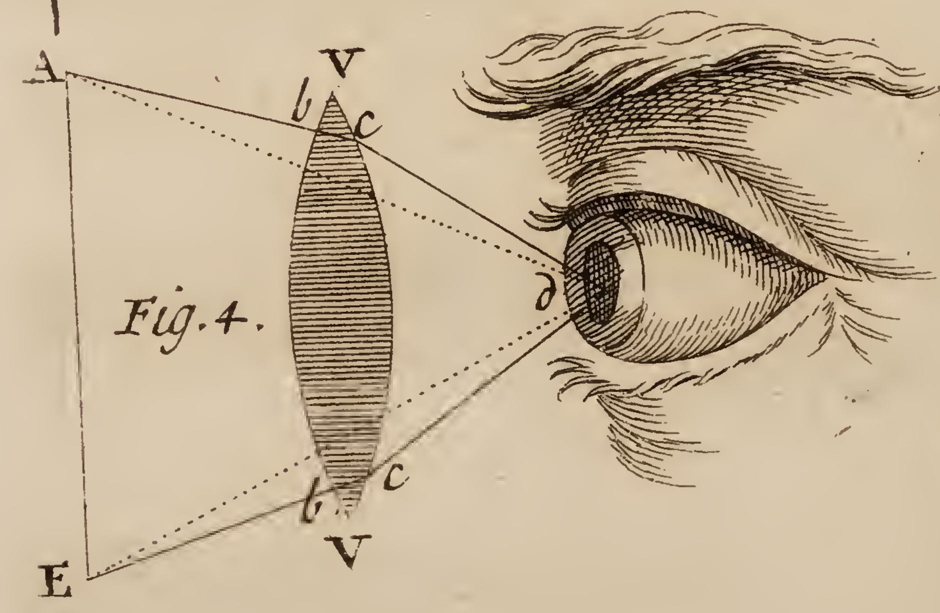


Fig. 5

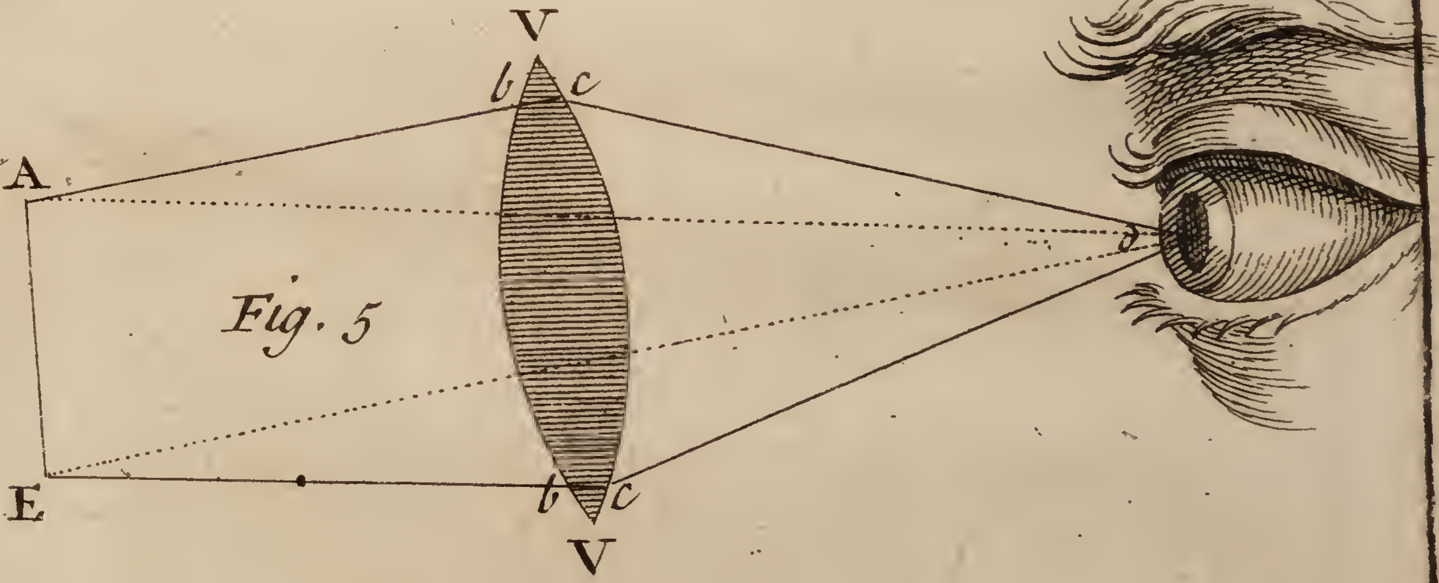
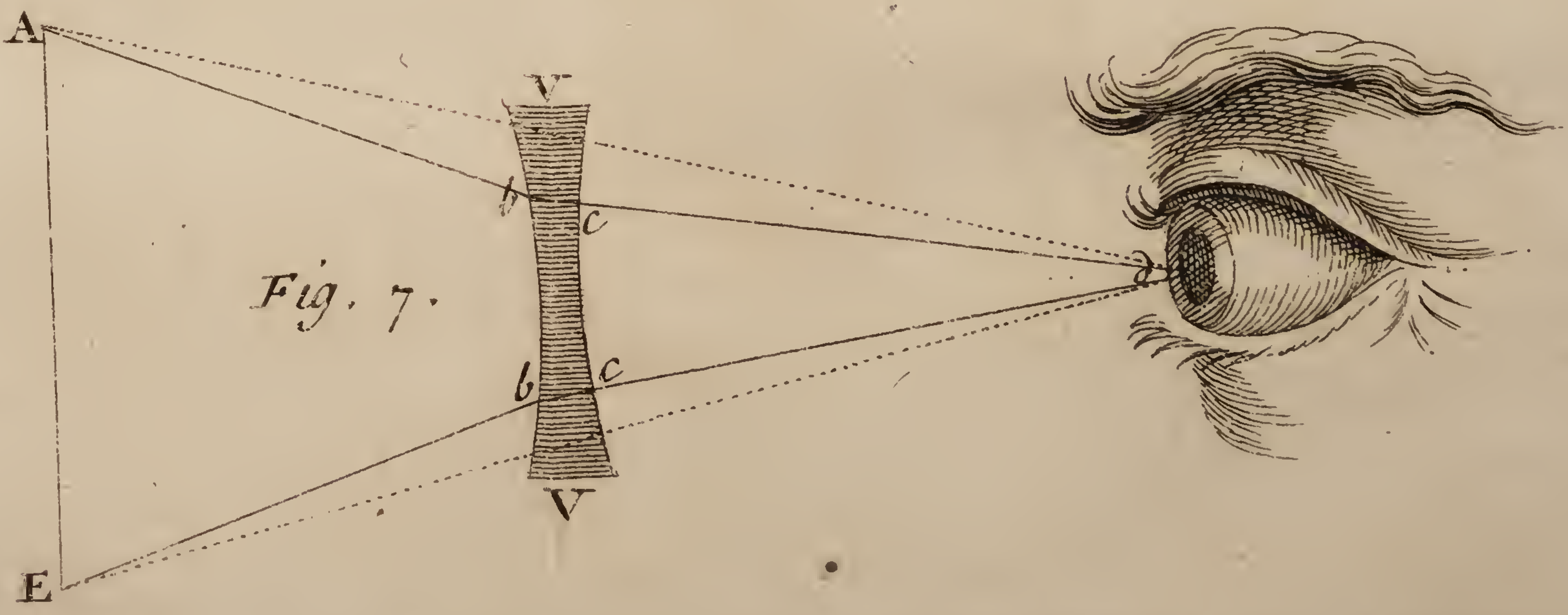


Fig. 7.



beyond the Lens, is leſs than the Angle A *d* E, under which it is ſeen by the naked Eye: therefore upon account of the Diminution, both of the Diſtance and the Angle abovemention'd, the Object appears diminiſh'd *. *734

A concave Lens is of uſe to thoſe who ſee no Objects 758 *diſtinctly, but ſuch as are near*; ſuch are call'd Myopes; thro' this Lens remote Points appear to be near, * and the Rays which did concurr be- * 757 fore they came to the Retina, now enter the Eye more diverging and meet upon the Retina.

There are Glaſſes that have one Surface plane, and the other Side is made of ſeveral plane Surfaces that make Angles one with another, (like a Diamond) thro' theſe the Rays that flow from one Point ſuffer different Refractions; and by every Surface are made to enter the Eye in a different Direction, as if they came from different Points: that is, the ſame Point forms ſeveral imaginary Foci; and therefore appears multiplied; for it is ſeen in ſeveral imaginary Foci *; * 737 which as it happens in reſpect of every Point of the Object, *thro'* ſuch *a Lens, which is a Polyhedron* (or Multiplying Glaſs) *the Object appears multiplied.*

C H A P. XII.

Of Microſcopes and Teleſcopes.

WE have ſhewn of what uſe Glaſſes terminated with ſpherical Surfaces are for correcting the Defects of the Eyes of Old Men and of the Short-ſighted *. How they ſerve for diſ- * 756 758 covering the ſmalleſt Objects, and bringing the moſt diſtant (as it were) to the very Eye, is what we are now to conſider.

We have ſaid that convex Glaſſes magnify the
747 Objects; which magnifying depends upon the Refraction of the Rays as they go thro' a convex Lens; whence it follows, that it is encreaſed, if, in the ſame Circumſtances, the Refraction be increaſed; which Effect may be produc'd, by augmenting the Convexity of the Lens; which will be the more convex as the Surfaces that terminate it are Segments of a leſs Sphere; which can only be had in very ſmall Glaſſes.

DEFINITION I.

760 Such ſmall Lenſes are call'd *Microſcopes.*

761 *By a Microſcope ſmall Objects are vaſtly magnified*; by which means, Things, which wou'd be inviſible to the naked Eye, are very diſtinctly ſeen.

DEFINITION II.

762 *The Space ſeen thro' the Microſcope, that is the Circle in which Objects are viſible thro' the Microſcope, is call'd the* Field of the Microſcope.

Experiment 1. *Plate* IX. *Fig*. 5.] If we look at the ſmall Object A E thro' the Microſcope V, it
*745 will appear magnified at *a e* *.

747 There are alſo compound Microſcopes, made up of two or three Lenſes; what Foundation they depend upon, will be ſufficiently ſhewn by explaining one of thoſe which is made up of two Lenſes.

Plate XI. *Fig*. 2.] Take a ſmall Lens that is very convex, as V V, and let the Object A E be plac'd at ſuch a Diſtance from it, that all its
*710 Points ſhall have their Foci beyond the Lens *;
699 let the Object be brought ſo near, that the Foci
*699 may be remov'd to *a e**, and you will there have the Repreſentation of the Object, very much enlarg'd,

enlarg'd, which will be ſenſible if you receive it there upon a white Plane *. * 711

Experiment 2. *Plate* XI. *Fig.* 1.] The Lens abovemention'd muſt be made faſt in the End of a Tube at V; and the other End of the Tube, which is wider, muſt be cover'd with a very thin Paper C C; the Object A E muſt be ſo plac'd, that the Foci of the Points of that Object ſhall be juſt at the Diſtance of the Paper: if then the Object be well enlighten'd, you will have its Repreſentation inverted, viſible thro' the Paper at *a e*. By moving the Object, you will have the true Poſition that brings the Repreſentation upon the Paper to be diſtinct.

Plate XI. *Fig.* 2.] All the Points of the Repreſentation *a e*, are radiant Points, and therefore viſible *; which being ſeen thro' a large Microſcope V V, ſhew the large Repreſentation *a e* at a e *; that is, the Rays coming from the Object A E, after their Refractions thro' both the Lenſes V V, V V, will enter the Eye, as if they came from an Object at *a e*. * 736 754 * 761

Therefore *thro'* ſuch *a compound Microſcope the Object appears inverted, and much more magnified than thro' a ſingle Microſcope.* 763

DEFINITION III, and IV.

In this Microſcope the ſmalleſt Lens, which is next to the Object, is call'd the Object-Glaſs, *and the other the* Eye-Glaſs. 764

This laſt ought not to be too ſmall; for the Points of the Repreſentation *a b*, tho' they be radiant Points, do not emit Light every way; only the Rays which paſs thro' the Object-Glaſs, interſect one another in the ſeveral Points of the Repreſentation *a b*; which Repreſentation therefore will not be viſible, unleſs the Rays that go thro' the Object-Glaſs do alſo go thro' the Eye-

765 Glaſs. *The Field* therefore (or the Space that the Microſcope can take in) *depends upon the Magnitude of this Lens.*

The Eye alſo muſt be ſo plac'd, that all the Rays that come to the Eye-Glaſs, going thro' it, ſhall come to the Eye; which is done by placing the Eye at *d, the Point in which all the Rays which come from the Center of the Object-Glaſs, and paſs thro' the Eye-Glaſs, are collected.*

Objects appear bright enough thro' Microſcopes, becauſe they are very near the Glaſs; and ſo the ſame Number of Rays paſs thro' a ſmall Lens, as wou'd not paſs at a greater Diſtance, unleſs thro' a greater Hole: *Yet often, where Objects are the moſt magnified, they muſt be enlighten'd by Rays collected thro' a convex Lens and thrown upon them.* 767

The Aſtronomical Teleſcope much reſembles the compound Microſcope.

DEFINITION III.

768 *Inſtruments fitted to ſee diſtant Objects, are call'd* Teleſcopes.

769 That which we now treat of is call'd the *Aſtronomical* Teleſcope, becauſe it is not ſo fit for ſeeing Objects upon Earth; for it repreſents them inverted: but Aſtronomers do not much regard the Poſition of the Appearance of the Object.

This Teleſcope conſiſts of two convex Lenſes, the one an Object-Glaſs, which is plac'd next to the Object, and the other an Eye-Glaſs, plac'd next to the Eye. By help of the firſt, diſtant Objects, are repreſented at a certain Diſtance behind the Lens *, as near Objects are in the compound Microſcope. If this Repreſentation be obſerv'd thro' an Eye-Glaſs, it will appear enlarg'd and inverted, as we have ſaid concerning the Microſcope.

* 711

It is plain alſo, that in this caſe, as well as in 770
the Microſcope, the *Field depends upon the Breadth
of the Eye-Glaſs*; as alſo that *the Place of the Eye* 771
*muſt be determined in the ſame manner for the Teleſcope as for the Microſcope** : For the Aſtronomic *766
Teleſcope differs from the Compound Microſcope
only in this, that in the Microſcope the Lenſes
are more convex, and therefore leſs proper for
looking at diſtant Objects, eſpecially in reſpect
of Object-Glaſſes. In the Microſcope, the Object-Glaſs is more convex than the Eye-Glaſs;
but the contrary obtains in the Teleſcope.

Teleſcopes cannot be too long for obſerving the Stars: but if they are above 20 Foot long, they are of no uſe for ſeeing Objects upon Earth; becauſe of the conſtant trembling of the Air, which is two ſenſible in Glaſſes that magnify very much.

A ſhort *Aſtronomic Teleſcope will ſerve to ſee* 722
Objects upon Earth, by adding to it two convex Lenſes,
which are alſo call'd Eye-Glaſſes; the three
Eye-Glaſſes are alike, and leſs convex than in
the Aſtronomic Teleſcope, the Object Glaſs remaining the ſame.

Plate XI. *Fig.* 3.] Take an Object-Glaſs V V, 773
which repreſents a diſtant Object at *e a*; then
take beſides three Eye-Glaſſes D D, D D, D D;
the firſt muſt be ſo plac'd, that the Rays coming
from the Points of the Repreſentation *e a*, ſhall
become parallel when they have paſs'd the Lens*; *699
in that caſe the Rays which come from the middle Point of the Object-Glaſs will be collected
at G; the Second Lens muſt be ſo plac'd, that
theſe Rays which are collected at G (where they
interſect one another, and move as if they came
from that Point) may go out parallel after they
have paſs'd thro' it *; which being perform'd, *669
the Rays coming from the Object-Glaſs to *e*,
and

and there interſecting and forming that Point of the Repreſentation of the Object, being refracted thro' the firſt Lens, paſs by G parallel to one another; thro' the Second Lens they are refracted in the Direction D e, and collected at e*, ſo as to make it the Point of a new Repreſentation. In the ſame manner the Point *a* of the firſt Repreſentation correſponds to the Point a of the ſecond Repreſentation; which being alſo true concerning the intermediate Points, there will be found an erect Repreſentation of the Object at a e. *698

Experiment 3. *Plate* XI. *Fig.* 4.] Let three little Boards D, D, D, with Eye-Glaſſes in them, that collect parallel Rays at the Diſtance of about 5 Inches, be moveable upon a Plane between two Rulers, in ſuch manner that the three Glaſſes may be in the ſame Line as the Hole V, thro' which alone the Light enters into the Room, and in which there is an Object-Glaſs, which is fix'd in a ſhort Tube, in order to exclude all the ſide Light.

This Object Lens is ſuch as is able, at the Diſtance of 3 Feet from V, to repreſent diſtant Objects inverted at F; which Repreſentation will be viſible, if you let the Rays fall upon a white Plane in that Place*. Five Inches farther from F, you muſt place the firſt Eye-Glaſs, and 10 Inches from that, you muſt place the Second; at *f*, which is five Inches from it, you will have an erect Repreſentation of the ſame Objects, which will alſo be viſible, if receiv'd upon a white Plane. *711

774 *Plate* XI. *Fig.* 3.] If the Repreſentation a e be ſeen thro' a third Eye-Glaſs, ſuppoſing the Eye at *o*, in which the parallel Rays a D and a E are collected, *the Object appears magnified, brought near, and erect*; for it is ſeen under the Angle

Do D, when with the naked Eye it wou'd appear under a very ſmall Angle; it will alſo appear near, becauſe, tho' it be ſeen beyond a e, yet the Diſtance at which it appears, has no ſenſible Relation to the Diſtance of a very diſtant Object.

Experiment 4. *Plate* XI. *Fig.* 4.] Suppoſing every Thing as in the foregoing Experiment; let there be a third Eye-Glaſs plac'd 10 Inches from the Second, and 5 Inches from that a little Board, or Eye-Stop, with an Hole O; if the Eye be plac'd at O, the Object, as has been ſaid, will appear erect, magnified, and near. If the Board O be diſplac'd, that is, be brought nearer or remov'd farther off, the Field of the Teleſcope is diminiſh'd; becauſe there is but one ſituation of the Eye, in which all the Rays which paſs thro' the Eye-Glaſſes can come to the Eye.

We are to take notice, that the Eye-Glaſſes made uſe of here, are not convex enough in reſpect of the Object-Glaſs V; but they are beſt for making the 3d Experiment.

All the Points of the Object do alſo *appear more* 775 *enlighten'd:* for the Rays which coming from any Point to the ſeveral Points of the Object-Glaſs, do interſect one another in a Point of the Repreſentation, by reaſon of the ſmall Diſtance of the Eye-Glaſs from that Repreſentation, are but little diſpers'd before they come to the Eye; ſo that they all go into it. And therefore the Illumination given by the Teleſcope, is to that which is given by the naked Eye, as the Surface of the Object-Glaſs, thro' which the Rays paſs, to the Surface of the Pupil.*

One may alſo *with two Lenſes make Teleſcopes,* 776 *which ſhall ſhew Objects erect, enlighten'd, and magnified.* Theſe muſt be ſhorter; for if they be above one Foot long, they become almoſt uſeleſs,

because

* 778

becauſe their Field will be ſo ſmall; that is, they will take in ſo little of an Object.

Plate XI. *Fig.* 5.] Let V V be an Object-Glaſs, the inverted Repreſentation of a diſtant
* 711 Object will be at *e a* *: the Rays are ſo intercepted by the concave Lens D D, that ſuch of them as come from the Center of the Lens V V, are inflected as if they proceeded from the Point
* 705 *f* *; by the ſame Refraction in the Rays which
* 706 concurr'd at *a*, become diverging *; having their imaginary Focus at a; which alſo happens in reſpect to all the Points of the Repreſentation *e a*, and inſtead of it, you have an imaginary Repreſentation which is erect at a e; that is, the Rays enter the Eye as if they came from the Object plac'd at a e.

777 The Rays, in all reſpects, go out diverging from the Eye-Glaſs; and therefore *the Eye muſt be brought as near as poſſible to the Eye-Glaſs.*

778 *In this Teleſcope, the Field depends upon the Bigneſs of the Object-Glaſs*; for the Rays which from a Point come obliquely to the Center of this Lens, very often do not enter the Eye; whilſt other Rays from the ſame Point, which paſs thro' the Lens near its Circumference, do come to the Eye.

CHAP. XIII.

Of the Reflection of Light.

WE have ſhewn that Light is reflected from opaque Bodies, and that every Point
* 710 reflects it every way *. The Occaſion of this is the Inequality of the Surfaces, which are made up of an innumerable Quantity of ſmall Planes, which, in all ſenſible Points, are directed every

Fig. 1.

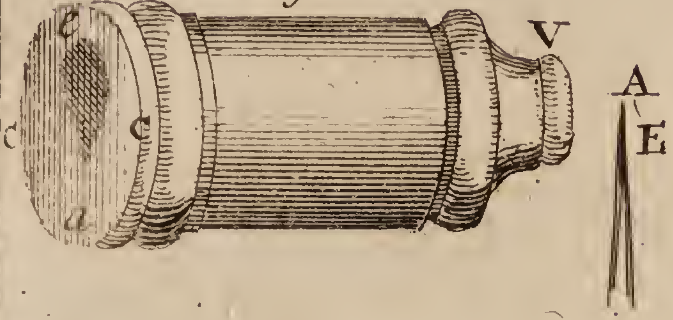


Fig. 2.

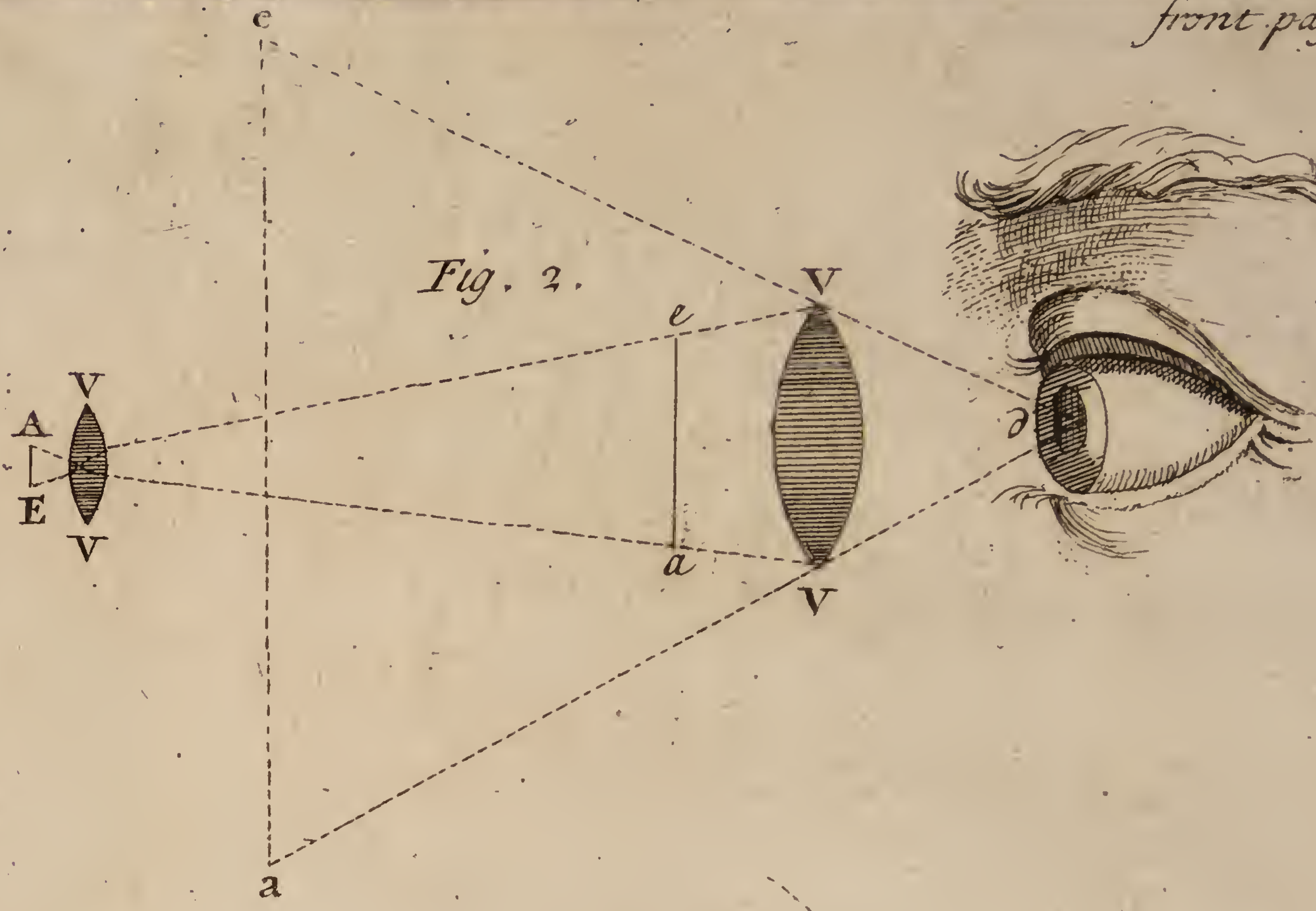

e
V
e
A
E
V
V
a
V
a
a
∂

Fig. 3.

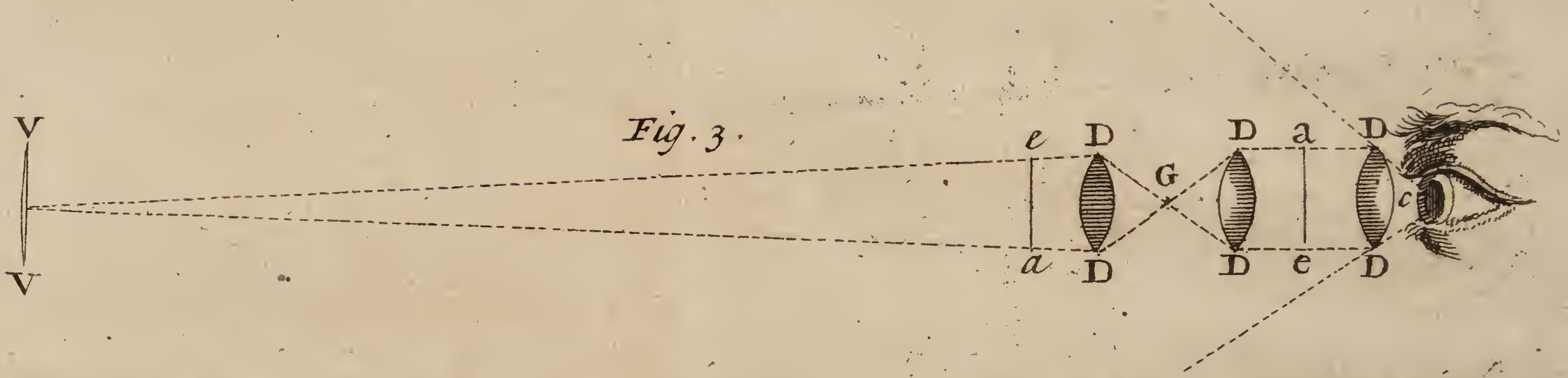

V
V
e
D
a
D
G
D
D
a
e
D
c
D

Fig. 4.

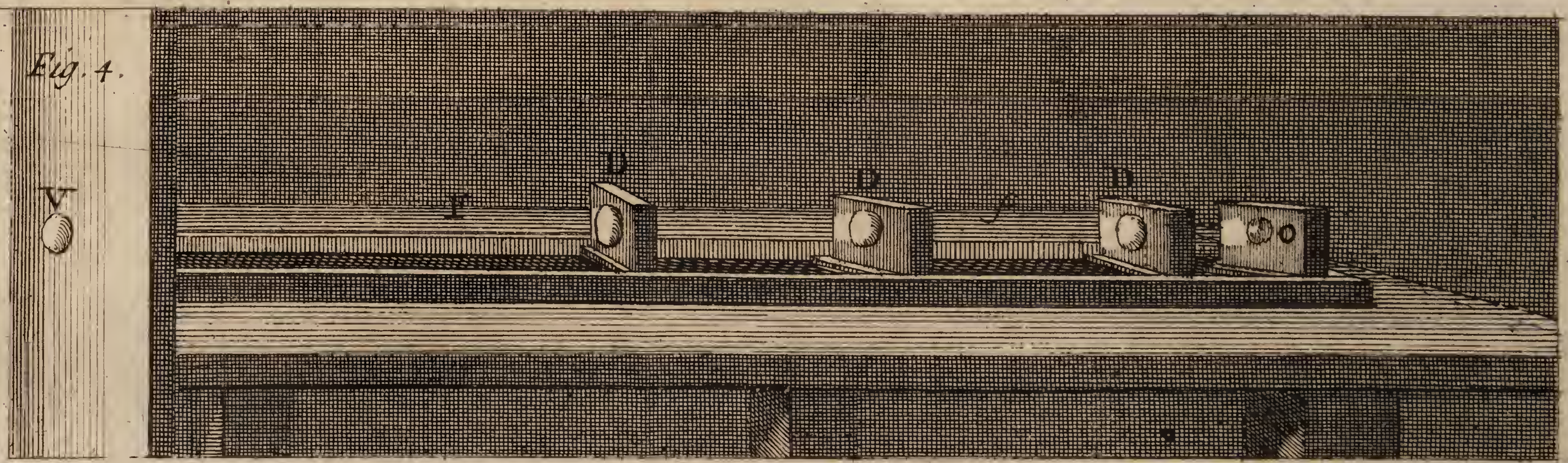
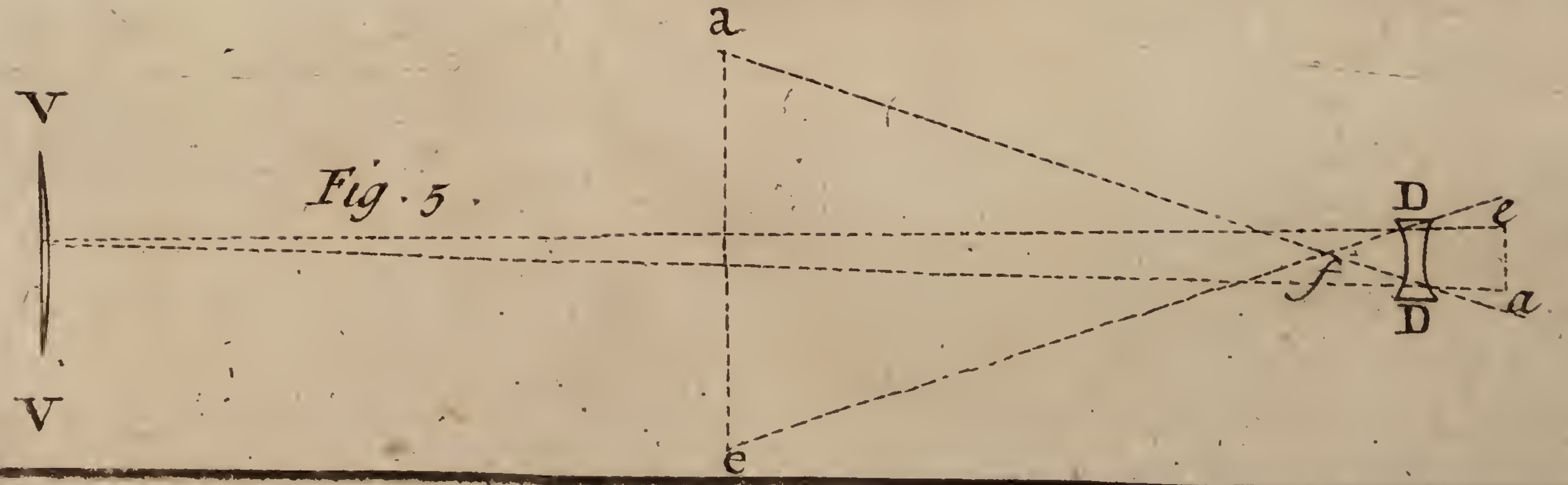


Fig. 5.



every Way; which will be eaſily conceiv'd, if we imagine a Surface cover'd with an innumerable Quantity of ſmall Hemiſpheres. That this is true, we deduce from the Reflexion of Light from a poliſh'd Surface; that is, from a Surface whoſe Inequalities are taken off; which in all its Points reflects the Light only one way, which holds in a Curve as well as in plane Surfaces: Nay, from Surfaces that are not at all poliſh'd, the Light is moſtly reflected that way, that it would be all reflected if they were poliſh'd, as daily Experience ſhews.

Plate XII. *Fig.* 2.] Let AC be a Ray of Light coming obliquely upon a plane Surface; let CO be perpendicular to this Surface, and the Ray be reflected along CB.

DEFINITION I.

The Ray CB, is call'd the *reflected Ray.* 780

DEFINITION II.

The Angle OCB is call'd the *Angle of Reflexion.* 781

The reflected Ray, together with the incident Ray, is in the ſame Plane which is perpendicular to the reflecting Plane. 782

For *the Action of this Plane, by which the Light is reflected, is directed perpendicularly* to a Plane, which is ſuppoſed like it in all Points. 783

The Angle of Reflexion is equal to the Angle of Incidence. 784

Experiment 1. *Plate* XII. *Fig.* 2.] Take a plane Looking-glaſs S, which may be ſet in any Poſition by means of a Ball and Socket join'd to the Foot that ſuſtains it; thro' a Hole, in the Plate of Metal L, that is in the Window, let in a Sun Beam of about a quarter of an Inch Diameter into the Room; the Glaſs muſt be ſo diſpoſed that the Beam may come thro' an oblique cylindric Cavity (of the ſame bigneſs as the Beam) made in a little upright Board **T**: If you turn this Board Side for Side, the reflected Ray will go thro' the ſame Cavity. This holds good, whatever the Inclination of the Cavity be, as may be demonſtrated by uſing different Boards.

By which Experiment N°. 779 is prov'd, as well as N° 784.

785 *Plate* XII. *Fig.* 2.] *If the reflected Ray becomes the incident Ray*; that is, if the Light comes along the Line B C, it will return in the Line C A, that is, the firſt *that was the incident Ray will become the reflected Ray*; as appears from the Equality of the Angles B C O, O C A.

From this Equality of the Angles of Incidence and Reflexion, we farther deduce, that *the Light after it has fall'n upon a Body, recedes from it with the ſame Force that it came upon it.* Let the Motion along A C be reſolv'd into two Motions along A O and O C *, ſuppoſing A O parallel to the reflecting Plane, and O C perpendicular to it. Let A O be continued; the Motion in that Direction is not alter'd from the Action of the Plane: Therefore let A O and O B be equal; if the Light recedes from the Plane with the ſame Force, with which it came upon it, the Motion occaſion'd by the Repulſion is repreſented by C O, and in that Caſe the reflected Ray goes thro' B *; that is, the Angle O C B is equal to the Angle O C A, which agrees with the Experiment.

* 192

* 190

787 As to the Reflexion of Light it is to be obſerv'd, that *Light does not run againſt the ſolid Part of Bodies, when it is reflected by them; but that it is reflected in thoſe Places, where it cou'd very freely paſs*

paſs. I ſhall prove this by ſeveral Experiments by which many other wonderful Properties of Reflexion are diſcover'd.

788 It is a common Experiment obſerv'd by every Body, that when Light is mov'd through any Medium; as for Example, Glaſs, Water or Air, it does not undergo a ſenſible and regular Reflexion; but that it is reflected there, where two Mediums of different Denſity are ſeparated; ſo it is reflected in the Surface of Water or Glaſs.

Cou'd Light in ſuch Quantity ſtrike againſt the Particles, juſt where the Mediums are ſeparated, whereas it moves thro' both the Mediums for a great Space without ſtriking againſt any ſuch Particles; Are there more of thoſe Particles near the Surface than elſewhere? 789 *Light* alſo *is more abundantly reflected in a denſer Medium, when it comes againſt the Surface of a rarer; than when on the contrary moving in a rarer Medium, it ſtrikes againſt the Surface of a denſer.*

Experiment 2. *Plate* XII. *Fig.* 3.] In a dark Place, in which the Light enters thro' an Hole in the Plate L, let there be plac'd a triangular Priſm of Glaſs A B; let the Light enter the Priſm thro' one Side; if it comes to the next Side, making an Angle of Incidence greater than 40 Degrees, it is wholly reflected, and does not at all penetrate into the Air; but Light moving in Air is never wholly reflected by the Glaſs.

But if the Reflexion be made by the ſtriking of Light againſt the ſolid Parts of Bodies, there muſt be more ſuch Parts in Air than in Glaſs; for if Light was reflected from the Glaſs itſelf into the Air, the Light would never come to the Separation of the Mediums; that the Light can alſo go out of Glaſs in the very Places, where it is reflected, is prov'd by following Experiments.

periments. Therefore in the Neighbourhood of the Glaſs there muſt be ſo many parts in the Air, that there may be no way for the Paſſage of the Light, to cauſe it to be wholly reflected into the Glaſs; but it is plain that there are no ſuch Parts, becauſe Light comes thro' the Air in all Directions quite to the Glaſs. Even in the ſame place of the Surface which ſeparates the Glaſs and Air, the Light which comes from one Side is reflected, whilſt that which comes from the other Side is tranſmitted. Which clearly proves that the Light is reflected in the very Place where it can go thro'.

790 *Experiment* 3. *Plate* XII. *Fig.* 3.] Every thing being as in the former Experiment, if the Obliquity of the Light be chang'd, part of it will paſs thro' into the Air.

Who wou'd conceive that Light, which paſſes from Glaſs into Air, and does not run againſt the ſolid Parts, ſhou'd all of it (by a little encreaſing the Obliquity) run againſt thoſe Parts; when in each Medium, as has been already ſaid, there are Pores and Paſſages in all Directions.

791 *Experiment* 4. *Plate* XII. *Fig.* 3.] Take a Glaſs triangular Priſm A B, moveable about its Axis; which is made ſo by fixing braſs Plates to its Ends, with braſs Wire perpendicularly fix'd to them: The Priſm muſt be ſo laid upon the Trough P, as that the ſaid Wires may bear upon the Brims of it, which are made a little hollow to receive them, yet ſo as to let them turn, that the Priſm may move freely about its Axis: Let it be ſo plac'd as to reflect the Light in the ſame manner as in the ſecond Experiment. Let the Trough be fill'd with Water up to the Priſm; then the Light, which ſtriking againſt

the Air, was wholly reflected, now running againſt the Water, does partly enter into it, and is only reflected in part.

Which Experiment does not at all agree with a Reflexion made by a Stroke upon the ſolid Parts.

In the third Part of this Book we ſhall alſo ſhew, that thin Plates which reflect Light, will tranſmit it, if they become thicker *. * 894

792 The fourth Experiment alſo proves that *the reflecting Power is ſo much greater, as the Mediums, which are ſeparated by a reflecting Surface, differ more in Denſity*; for Glaſs and Air differ more in Denſity than Glaſs and Water.

793 In this Experiment we alſo ſee that *Reflexion is made by the ſame Power by which the Rays are refracted, which produces different Effects in different Circumſtances.*

A Ray, which goes out of a denſer into a rarer Medium, by the Attraction of the former, is made to recede from the Perpendicular *; if * 625 the Obliquity of the incident Ray be encreas'd, the Obliquity of the refracted Ray will alſo encreaſe, till it comes at laſt to move in the very Surface which parts the Mediums. And this obtains, when the Sine of the Angle of Incidence is to the whole Sine, as the Sine of Incidence in the denſer Medium, is to the Sine of Refraction in the rarer; for in that Caſe the Angle of Refraction is a right one. If the Obliquity of the incident Ray be more encreas'd, it is plain that the Ray cannot penetrate into the rarer Medium: This is the Caſe in which the Light is wholly reflected; which Reflexion depends upon that Attraction by which the Rays are refracted. For when the Ray is mov'd thro' the Space of Attraction, it is bent towards the denſer Medium *; if it be in the denſer Medi- * 619

um,

um, and ſo bent, that before it has gone thro' the whole Space of Attraction, the Tangent to the Curve be parallel to the Surface that ſeparates the Mediums, the Curve being continued, turns back again; and therefore the Ray is reflected by the Attraction of the denſer Medium, and this Continuation of the Curve is ſimilar and equal to the firſt Part, and makes the Angle of Reflexion equal to the Angle of Incidence; becauſe the Light returns thro' the ſame Part of the Space of Attraction; and the ſame attracting Force acts upon the Light in correſpondent Points of the two Parts of the Curve. Thus a Projectile, in its Aſcent and Deſcent, deſcribes ſimilar Curves.

Yet that *all Reflexion does not depend upon that*
794 *Attraction in the ſame manner*, is evident; for in that Caſe in which the Refraction is made, part of the Light is reflected; for the Light does not wholly penetrate out of the rarer into the denſer Medium; for even in that Caſe, in which the Attraction is the moſt oppos'd to the Reflexion that is poſſible, yet ſome Rays are reflected.

Yet it cannot be doubted but that *in every*
795 *Caſe Reflexion has relation to the refracting Power.*
796 *Where Light paſſes without Refraction, there it is*
* 617, *not reflected* *; *but where the Refraction is greateſt,*
788. *there the Reflexion is alſo ſtrongeſt* *; which is true,
* 631, not only when Light, moving in a denſer Medi-
792. um, ſtrikes againſt a rarer, as in the fourth Experiment; but the ſame thing is obſerv'd, when Light ſtrikes againſt the denſer Medium: Thus ſuppoſing the Light to move in Air, the Surface of Glaſs reflects more ſtrongly than that of Water; and that of a Diamond yet more ſtrongly. If Glaſs and a Diamond be immers'd in Water; the refracting Power is leſs in the Separation of thoſe Bodies with Water, than where

thoſe Bodies touch the Air *. Theſe Bodies alſo * 631
reflect Light leſs ſtrongly in Water than in Air. From this Relation of the reflecting and refracting Powers we deduce, that *Light is driven* 797
back at a certain Diſtance from the Bodies, in the ſame manner that the refracting Power does alſo act at ſome Diſtance from the Body: This Propoſition is confirm'd from what has been demonſtrated concerning Reflexion, which does not depend upon a Stroke made againſt the ſolid Parts of Bodies; and this is fully made out if we conſider, that *poliſh'd Bodies reflect the Light* 798
regularly (which we obſerve in Looking-glaſſes) *tho' there be a great many Scratches in their Surfaces:* For as they are poliſh'd with the Powders of *Emery* and *Putty*, tho' their Parts are very ſmall, yet they leave very great Scratches on the Surface in reſpect of the Particles of Light; whence in the Surface itſelf the Reflexion muſt needs be irregular; but if we conceive the Reflexion to be made at ſome Diſtance from the Surface, the Irregularities are diminiſh'd, and almoſt wholly taken off, as is eaſily underſtood by any one that conſiders it with Attention.

CHAP. XIV.

Of Plane Mirrors.

Plate XII. *Fig.* 4.] LET *b c* be the Surface of a Plane Mirror or Looking-glaſs; A a radiant Point. *Let the Plane of the Glaſs be continued, and from the Radiant* A *let a Perpendicular* A C *fall upon it; if this Line be continued, and* C *a be made equal to* C A, *a will be the imaginary Focus of the reflected Rays that proceed from* A. Let A *b* be the incident Ray; *b f* the reflected Ray; which continue beyond the Glaſs; 799

the Angles of Incidence and Reflexion are equal
* 784 to one another *, their Complements alſo, which
are the Angles A *b* C, *f b d* are equal; to this is
equal its oppoſite and vertical *a b* C: The Triangles A *b* C, *a b* C, which are rectangular, have the
Side C *b* common, and the Angles C *b a*, C *b* A,
equal; therefore they agree in all reſpects, and CA
and C*a* are equal to one another: Which Demonſtration may be applied to all the other Rays
which flow from A, in whatever Plane, perpendicular to the Glaſs, they be conceiv'd to be.
Therefore wherever the Eye is, if the reflected
Rays come to it, they will enter the Eye as if
they came from *a*; and the Point A will appear
* 737 in that Place *; but *the Appearance of that Point*
800 *will have the ſame Poſition in reſpect of the Mirror,*
behind it, as the radiant Point has before it.

801 If this be applied to all the Points of the Object, it will appear, that *the Object will appear behind the Glaſs in the ſame Poſition that it has before the Glaſs.*

CHAP. XV.

Of Spherical Mirrors.

EVERY ſpherical Surface may be conſider'd, as made of innumerable ſmall Planes; and a Plane which touches the Sphere in any Point, is as it were a Continuation of ſuch a ſmall Plane.

Spherical Mirrors are either *Concave* or *Convex*.

The firſt are made of part of an hollow Sphere poliſh'd.

The ſecond are parts of Spheres poliſh'd on the outſide.

A Ray coming upon any ſpherical Mirror, together with its reflected Ray, is in a Plane, which being continued, goes thro' the Center of the Sphere *, for ſuch a Plane is perpendicular to the Surface of the Sphere. *A Line which is drawn thro' the Center of the Sphere and Point of Incidence, being continued, makes equal Angles with the incident and reflected Rays* *; for that Line is perpendicular to the Surface, and thoſe Angles are Angles of Incidence and Reflexion: Therefore *the Ray that goes thro' the Center, or which being continued wou'd go thro' the Center, when reflected returns upon itſelf.* 804 * 782 805 * 784 806

Plate XII. *Fig.* 5.] Let *bc* be a Portion of convex Mirror; A a radiant Point; let A *b*, A *d*, A *c*, be incident Rays; the reflected Rays will be *b f*, *d g*, *c h*; *if from the radiant Point* A, *a Tangent be drawn to the Mirror*, the reflected Ray will be a Continuation of the incident, or rather *the Reflexion of the Rays is terminated in the Point of Contact.* 807

If b f, d g, c h, the Rays that are reflected from the convex Mirror, be continued, with all the intermediate ones, by their Interſections they will form the Curve *a a*, which all theſe Rays touch, and the neighbouring Rays interſect in the Periphery of the Curve; ſo that they always enter the Eye as if they came from a Point of the Periphery; *in which* therefore *the Point* A *does* always *appear* *, as long as the reflected Rays can come to the Eye, and the Eye is mov'd in a Plane which goes thro' the Center of the Sphere; but when the Eye is remov'd out of that Plane, the radiant appears in another Curve, becauſe there are ſuch Curves in every Plane, which may be conceiv'd to paſs thro' A and C. 808 * 737

Since all theſe Curves, and each of them wholly are behind the Glaſs, *all the Objects* alſo *appear behind the Surface of the Glaſs.* 809

The

810 *The Objects* likewiſe *appear erect.* For if the Point A be mov'd about the Mirror, the whole Curve *a a* is carried with the ſame Motion; which proves (in reſpect to the erect or inverſe Situation) that the Points of the Repreſentation have the ſame Relation to each other as the Points of the Object itſelf.

As the Point A is farther remov'd from the Glaſs, the whole Curve does alſo recede by a contrary Motion; for ſuppoſing A at an infinite Diſtance, that Point of the Curve which is the fartheſt remov'd from the Surface, will be diſtant from it a quarter of the Diameter; whence it
811 follows, that *the Objects appear diminiſh'd,* becauſe all the Repreſentations are compris'd in ſmall Limits.

812 *If the Eye be mov'd, the Appearance of the Object is alſo mov'd, and its Figure chang'd:* For all the Points are mov'd in their own Curves, and that unequally, according to the different Situation of the Eye in reſpect of each Curve; whence of Neceſſity the Figure muſt be chang'd.

Experiment 1. *Plate* XII. *Fig.* 6.] If any one ſees his Face in a ſpherical convex Mirror, ſtanding at A, he will ſee his Face at *a* erect, diminiſh'd and unlike; by the Motion of the Eye one may obſerve the other Things mention'd in reſpect to fix'd Objects.

813 *Let b d (Plate* XIII. *Fig.*1.*)* be *a concave Mirror,* and a Portion of a Sphere whoſe Center is C; *let parallel Rays fall upon the Surface of the Mirror,* one of which, C *d*, is ſuppos'd to paſs thro' the Cen-
* 806 ter; this Ray by Reflexion returns upon itſelf*, and the Rays next to it being reflected, become converging, and concur with it in the Focus F, which is the middle Point between *d* and C. Let A *b* be a Ray very little diſtant from C *d*; draw the

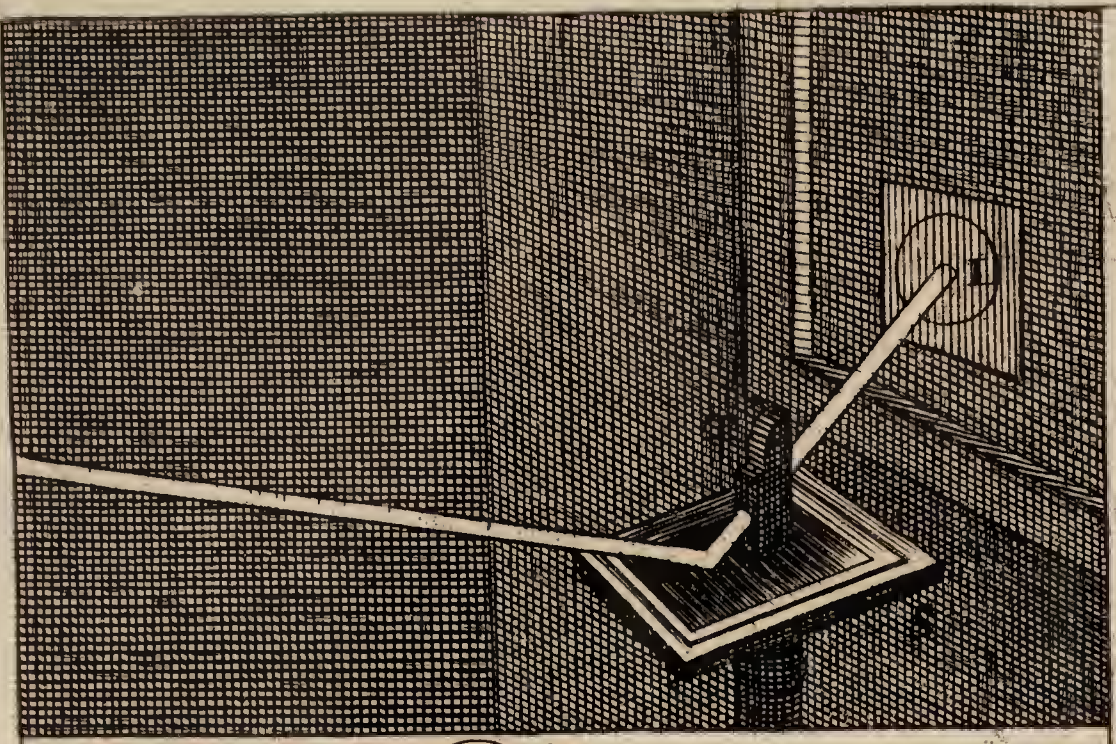


Fig. 1.

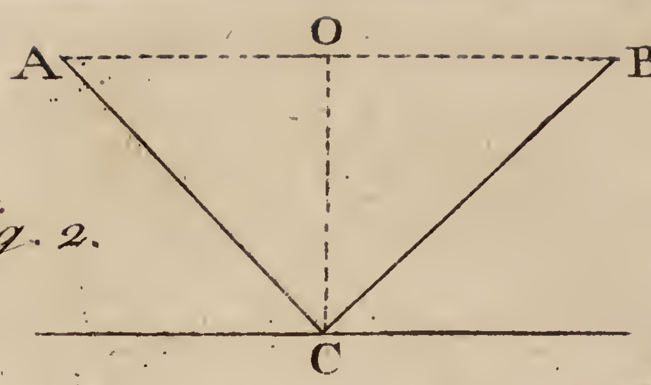


Fig. 2.

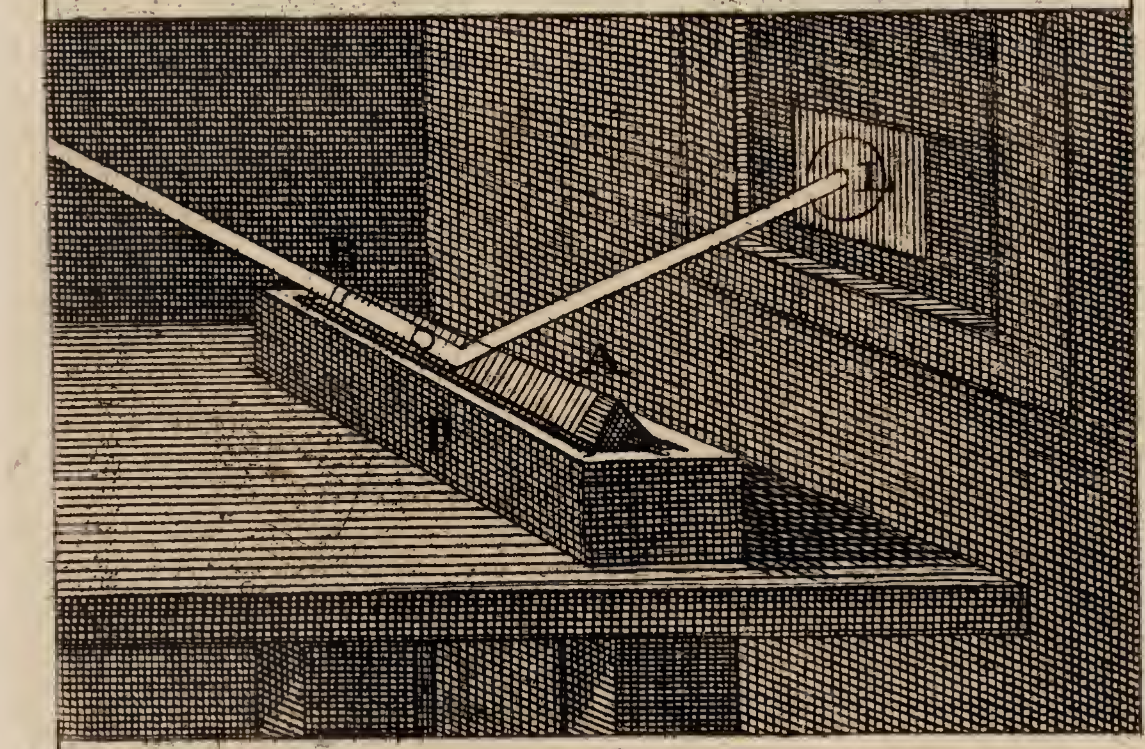


Fig. 3.

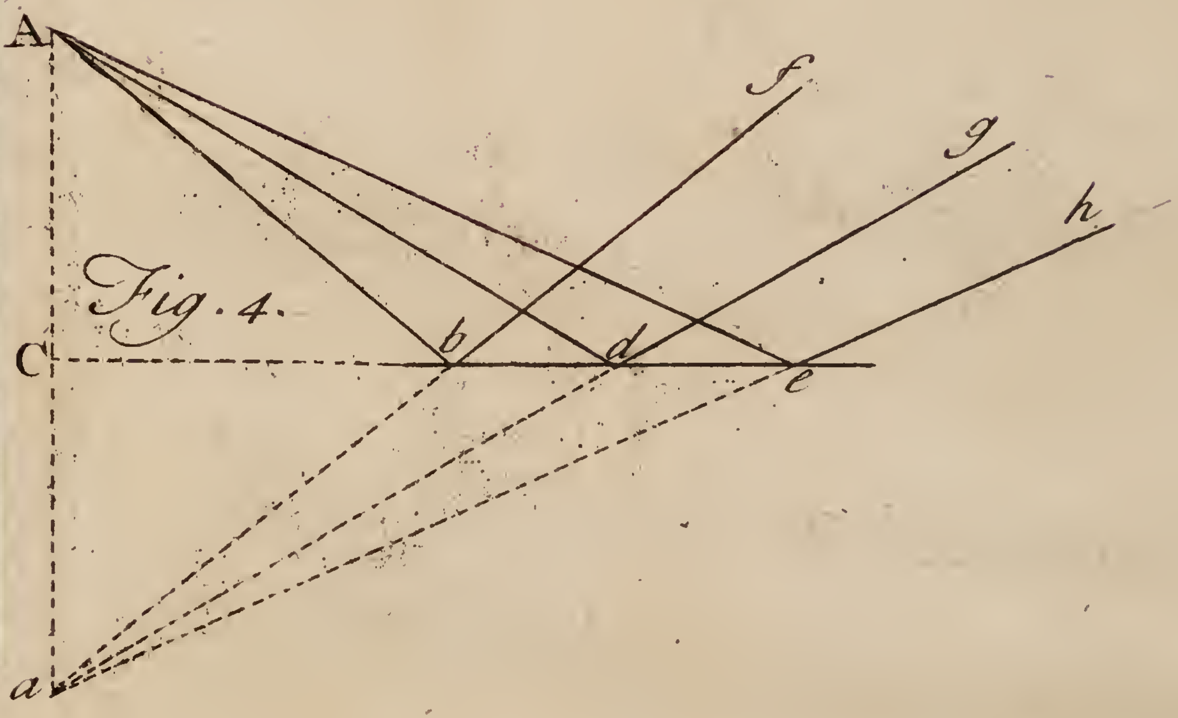


Fig. 4.

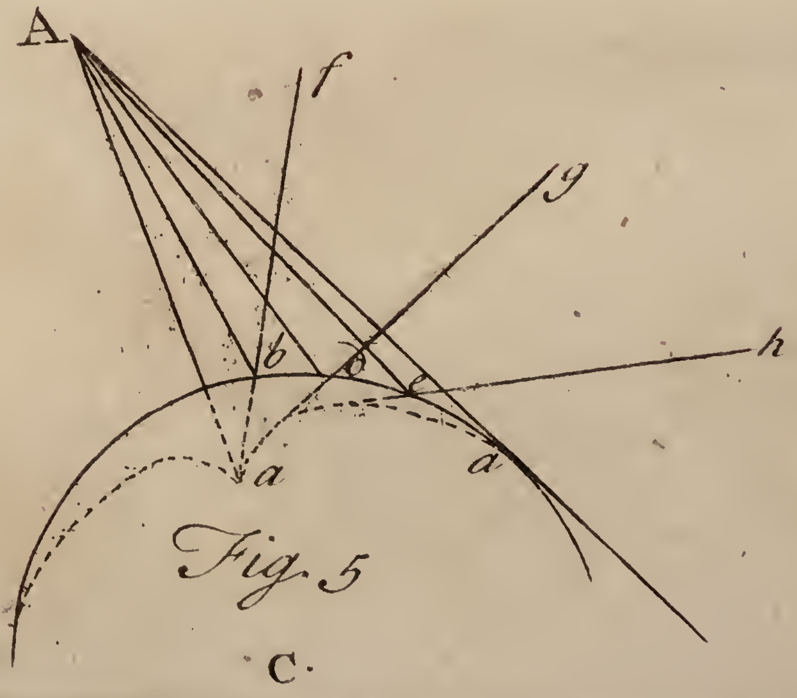

A
f
g
h
b
d
e
a
a
C.

Fig. 5

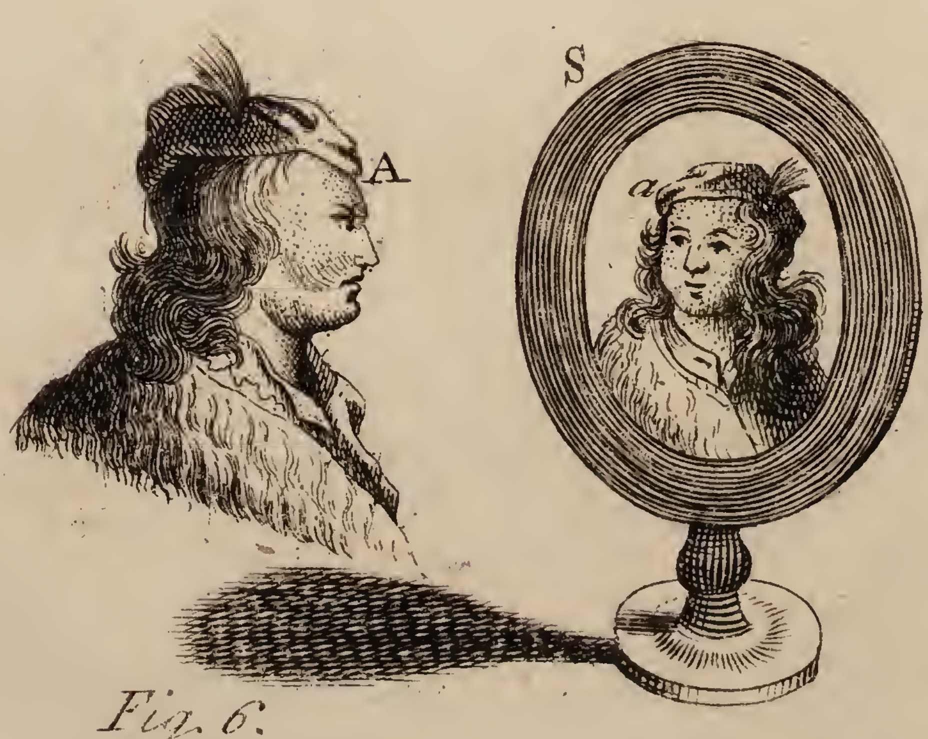


Fig. 6.

the Semidiameter C*b*; the Angle of Incidence will be A*b*C, to which the Angle of Reflexion C*b*F * is equal, as alſo the alternate Angle *b*CF; therefore *b*FC is an Iſoſceles Triangle, and the Sides FC and F*b* are equal; becauſe *bd* is very ſmall, F*d* and F*b* do not ſenſibly differ; therefore FC and F*d* are equal; which Demonſtration will ſerve for all the Rays that are but very little diſtant from C*d*. * 805

If parallel Rays are farther diſtant from C*d*, they do not meet at F; yet they will all come together into a little Circle, if the Diameter of the Mirror does not exceed the fifth or ſixth Part of the Diameter of the Sphere of which it is a Portion.

Burning Mirrors are made upon this Foundation, which collect the Sun's parallel Rays into a Focus. 814

Experiment 2. *Plate* XIII. *Fig.* 2.] Let there be a concave Mirror S, made of Metal, or of Glaſs quickſilver'd behind; let it ſtand upon the wooden Foot P, whoſe upper Part is bor'd ſo as to receive a Cylinder of Wood made faſt to a tranſverſe Piece A A, which ſerves for turning the Glaſs round with a horizontal Motion; and the Mirror itſelf muſt move upon two Ends of an Axis between the Pillars AB, AB, ſo as to be inclin'd in any Angle; and the Screws B, B, will make it faſt in any Poſition.

Having expos'd the Burning-Glaſs to the Sun-Beams in ſuch a manner, that the Ray which comes upon the middle of the Glaſs is perpendicular to its Surface; ſince all the others are parallel to it, they are collected in a Focus, at a quarter of a Diameter's Diſtance from the Glaſs, and there burn violently.

If the Diameter of the Surface of the Mirror (as it is in mine) be of about 15 Inches, and the Focus is 18 Inches diſtant from it, Wood will immediately be in a Flame, and thin Plates of Lead preſently melt.

If we conſider the Rays that are at ſome Diſtance from C *d*, and parallel to it, thoſe of
them that are neareſt one another being reflected, will interſect before they come to C *d*, and
815 in that Caſe, that is, *where parallel incident Rays
fall obliquely on the Glaſs, being a little diſpers'd by
Reflexion, they are collected in a Point.*

816 *If the Focus, in which parallel Rays are collected
by a concave Mirror, becomes the radiant Point*, the
Rays which are but little diſperſed, are refle-
* 813, cted parallel to one another *.

785. From theſe Properties of a concave Mirror
817 we deduce the Method of repreſenting Objects
in a dark Place, much like what was before
ſhewn in reſpect of a Convex Lens *.

* 711 *Plate* XIII. *Fig.* 3.] Let there be an Hole F
thro' the Wall; let a b be a concave Mirror, ſo
plac'd as to collect the parallel Rays that are
perpendicular to the Wall at F: The Rays com-
* 816 ing from F in that Direction, are reflected *,
and ſuch are the Rays, which being reflected
from the external Objects, interſect one another
at F.

Let A F be Rays coming from a Point of a
diſtant Object; theſe Rays are by the Mirror
reflected perpendicularly to the Wall; and be-
cauſe Rays coming from a diſtant Point, and
paſſing thro' a ſmall Hole, may be look'd upon
as parallel, theſe Rays will, after Reflexion, be
collected into one Point at *a*, at the Diſtance of
* 815 the Wall *, that is in its Surface; where there-
fore the Point will be repreſented. In the ſame
manner the Rays which come from a Point
through

through B F, are collected at *b*; which, as it is true with Regard to all the Points of an Object, will give the Repreſentation of it upon the Wall: And if the Wall be white, and the Object enlighten'd by the Rays of the Sun, the Picture will appear in very lively Colours.

Experiment 3. *Plate* XIII. *Fig.* 4.] In a dark Place cover the backſide of the Window-ſhut with white Paper, an Hole being made in the middle of it little more than half an Inch Diameter, ſo as to anſwer to an Hole behind it in the Window-ſhut, over againſt which, at a Diſtance no leſs than of 50 Foot, there are ſeveral Objects enlighten'd by the Sun: Let a concave Mirror whoſe Surface is 15 Inches wide, and which collects parallel Rays at the Diſtance of 18 Inches, be placed at that Diſtance from the Window, in ſuch manner, that a Line paſſing thro' the Center of the Hole, and the Center of the Surface of the Mirror, be perpendicular to the Plane of the Paper and the Surface of the Glaſs. Then the Objects will be repreſented upon the Paper in a Circle concentric with the Hole, and whoſe Diameter is equal to the Diameter of the Mirror. You muſt join to the Hole, on the outſide of the Room, an hollow, truncated Cone, to exclude the Light which does not come from the Objects to be repreſented.

818 Let *b e* (*Plate* XIII. *Fig.* 5.) *be a concave Mirror*; C the Center of its Concavity; A *a radiant Point farther diſtant than* C *the Center of the Glaſs*; A *b*, A *d*, A *e* incident *Rays*, whoſe *reflected* ones *b f*, *d g*, *e h*, with their intermediate ones, *by their mutual Interſections form the Curve a a, which they all touch*; therefore *the Point* A *appears in that Curve*[*]; and if the Eye be mov'd in the Plane of the Curve, the Appearance will change Place

[*] 808

Place in that Curve. But in all the Planes which may be conceived to paſs thro' C A, there is ſuch a Curve, and they all concur in the Line
819 C A, namely at the Point *a*. *Therefore in that Point a, the reflected Rays are the moſt abundantly collected,* which therefore is call'd the Focus of the Rays coming from A. On the contrary, A
* 785 will be the Focus, ſuppoſing the Radiant at *a* *.

In this Figure there is only part of the Curve drawn, which is produc'd by one part of the Line A C; ſuch another Part muſt be conceiv'd on the other ſide, and both join in the Focus of the radiant Point.

820 *As the radiant Point recedes, the Curve comes nearer to the Mirror.*

821 As the Radiant comes forward, the Curve recedes from the Mirror, and moves toward the Radiant; till they concur *at the Center* C; in which, *if the Radiant be plac'd, all the reflected*
* 806 *Rays will coincide with the incident* *, and the whole Curve will, as it were, be ſwallow'd up in the Center.

822 *If the Radiant* is yet brought nearer to the Mirror, ſo as to *be between the Center and the Glaſs, the Curve will* recede farther, and *be* then *beyond the Center*; and in the Curve, that Point will recede moſt of all, in which all the Curves concur which are conceiv'd in ſeveral Planes, that is, the Focus of the radiant Point: and that Focus
823 will be at an infinite Diſtance, *when the Radiant is diſtant from the Mirror juſt the fourth Part of the*
*813 *Diameter of the Sphere.** Then alſo *the Curve is*
816 *extended in infinitum, and the two Parts* which concur in the Focus of the Radiant *are ſeparated*; this ſeparated Part is ſeen at a a: (*Plate* XIII. *Fig*. 6.) *If the Radiant be brought ſtill nearer, the Curve Parts decline from one another,* becauſe the Rays, ſuch as A *b*, and thoſe near it being reflected,

flected, do not touch the Curve, but become divergent; that is, thoſe reflected Rays being continued beyond the Glaſs, will interſect one another, *and form a new Curve behind the Glaſs, which has two Legs,* one of which is ſeen at *a a*; they concur in the Line C A continued, namely, at *a*, and receding from the Glaſs, are ſtretched out *in infinitum.* And there is alſo on each Side of the radiant Point, a Point in the Surface as *d*, which ſeparates the Rays that form the Curves *a a* and a a; and the Ray A *d* being reflected in *d g*, touches neither of the Curves, if it be infinitely continued toward each Part *g*, *g*, tho' it is continually coming nearer to each Curve. If the whole Sphere was compleated, in reſpect of the oppoſite Part of the Sphere, the Radiant would be beyond the Center, and the reflected Rays would form the Curve which we have mention'd before,* by which the ſeparated Legs, as a a, would be join'd. Theſe things thus premiſed, we proceed to explain the Phænomena of concave Mirrors. *818

825 *If the Mirror be enlightened by a lucid Body, the Rays which come from all the Points of the Object being reflected,* will form Curves, but *are chiefly collected in the Foci of theſe Points*;* therefore *if theſe Foci are in the Surface of a white Plane, there will be upon it a Repreſentation of the lucid Body,* as in the ſecond *Experiment* of *Chap.* IX. and that Repreſentation will be *inverted*; for the Line which joins the radiant Point with its Focus, goes thro' the Center of the Sphere;* in which therefore all ſuch Lines interſect one another; and this Interſection is between the radiant Point and the Focus,* in which the Point is repreſented. *819 826 *819 *818

But as the lucid Body is brought nearer to the Mirror, the Appearance recedes farther, and* in this Caſe *becomes bigger.* *820

Experiment 4.] Hold a lighted Candle between the Mirror and the Center of the Sphere of which it is a Portion; yet ſo that it may be more diſtant from the Mirror than that Center: If then there be a white Plane perpendicular to the Line that paſſes thro' the Candle and the Center of the Mirror, and this Plane be held beyond the Center, you will have upon it an inverted Repreſentation of the Candle; the proper Place will be found by moving the Plane forwards and backwards; as likewiſe by this Proportion, *viz.* as the Difference of the Diſtances of the Candle from the Center of the Sphere and from the Mirror, is to the fourth part of the Diameter of the Sphere, ſo is the Diſtance of the Candle from the Glaſs, to the Diſtance requir'd. As the Candle is brought nearer to the Speculum, the Plane muſt be mov'd farther off, and the Repreſentation will grow bigger.

827 *Plate* XIII. *Fig.* 5.] *Objects placed beyond the Center, appear between the Glaſs and the Center*, for
*818 all the Points appear in a Curve as at *a a*;* *the*
828 *Images of the Objects will alſo be diminiſh'd and inverted:* for they are reduced into a narrow Space; and as the Point A moves downwards, its Repreſentation will be carried upwards; for the Line *a a* keeps the ſame Situation in reſpect of A C *a* as it is carried round the Center C.

Experiment 5. *Plate* XIII. *Fig.* 7.] Leaſt the Repreſentation of the Objects ſhou'd be leſs vivid, the Mirror is to be included in a Box. If you have a Mirror, whoſe Surface is about 8 Inches wide, and which is a Portion of a Sphere of one Foot and a half in Diameter; ſhut it up in a Box P, in whoſe Fore-Part there is an Hole of

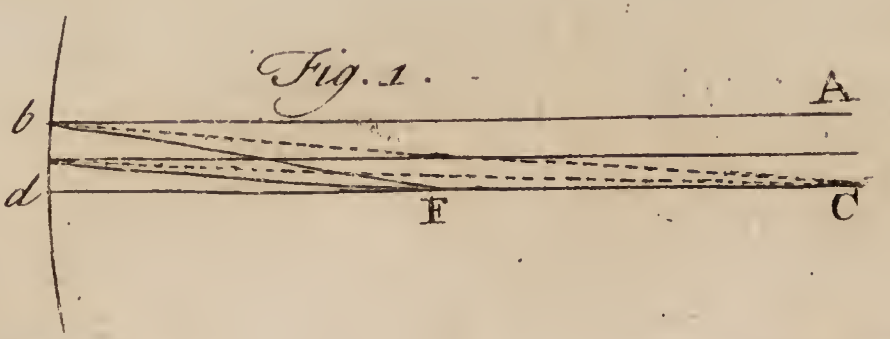


Fig. 1.

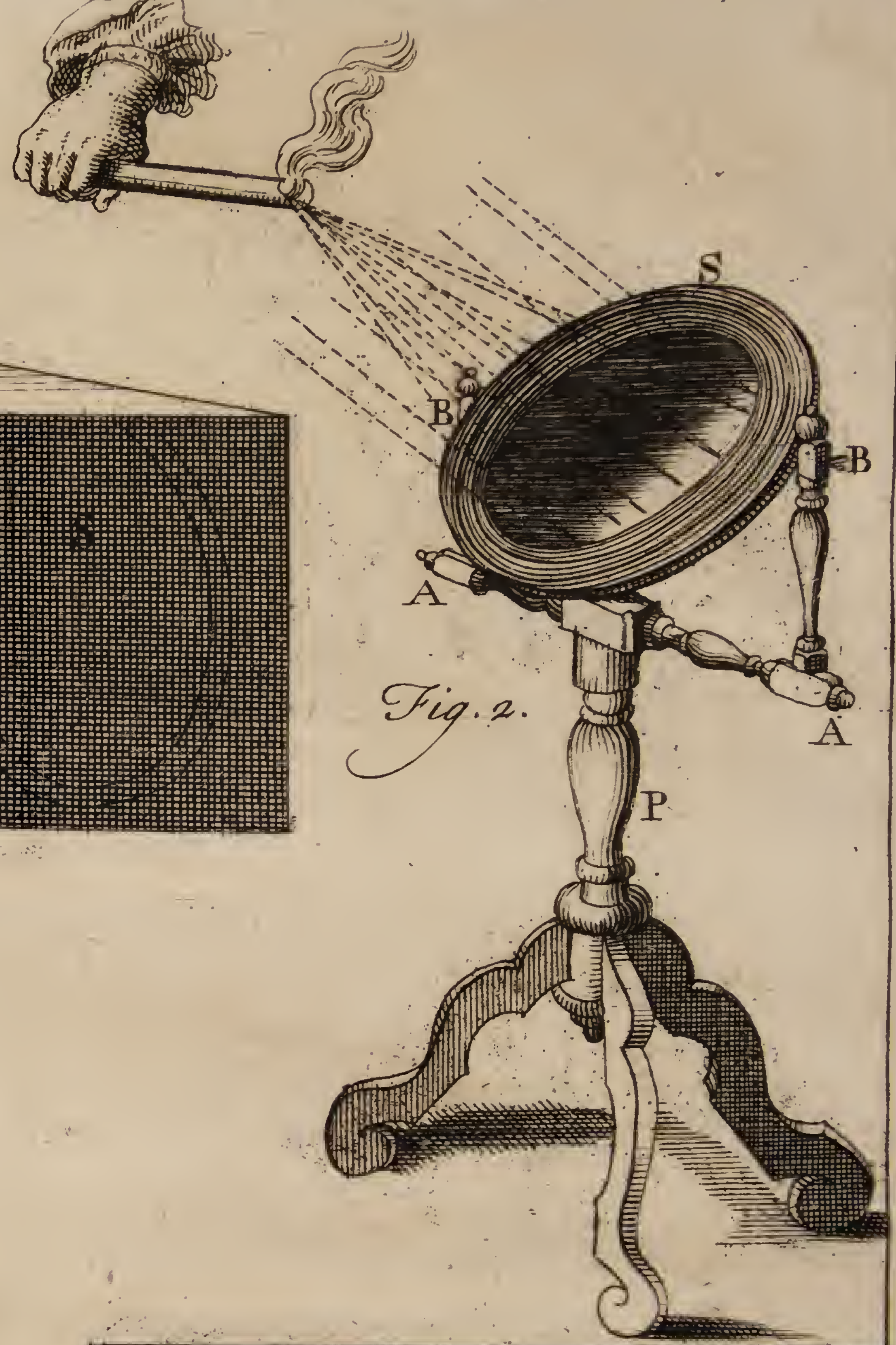


Fig. 2.

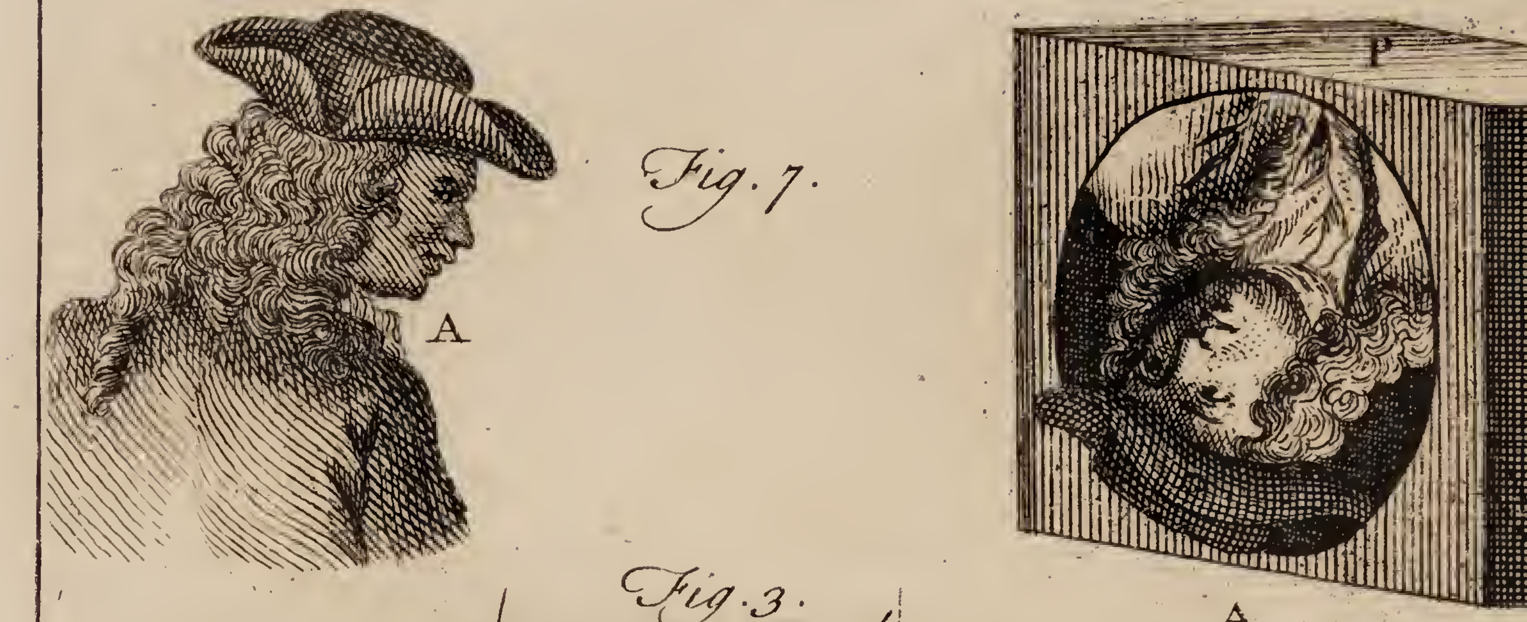


Fig. 7.

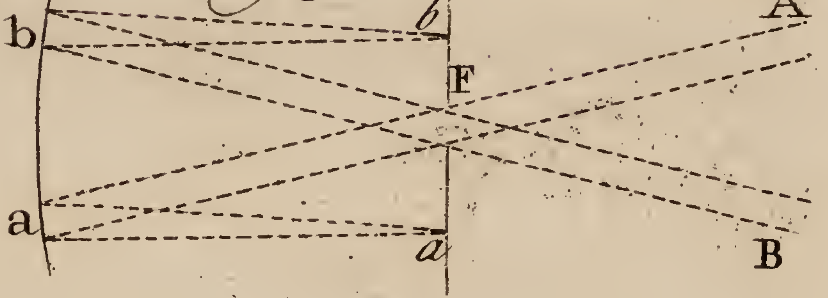


Fig. 3.

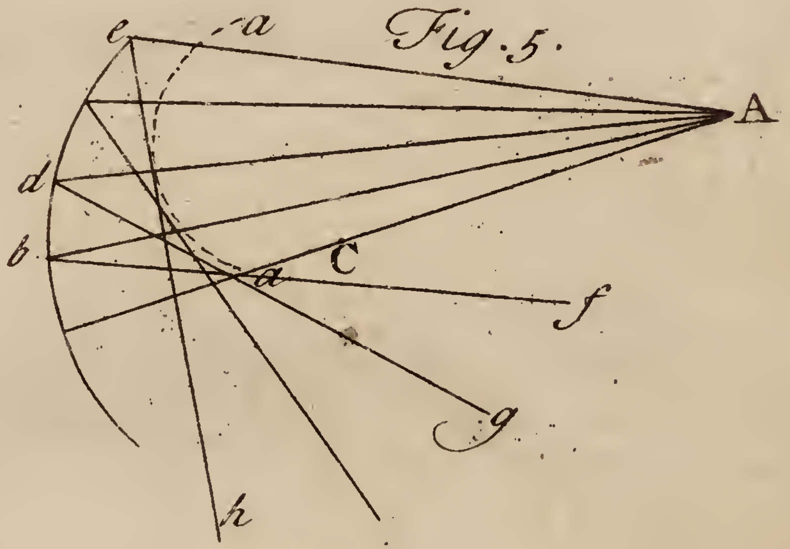


Fig. 5.

e
a
A
d
b
C
a
f
g
h

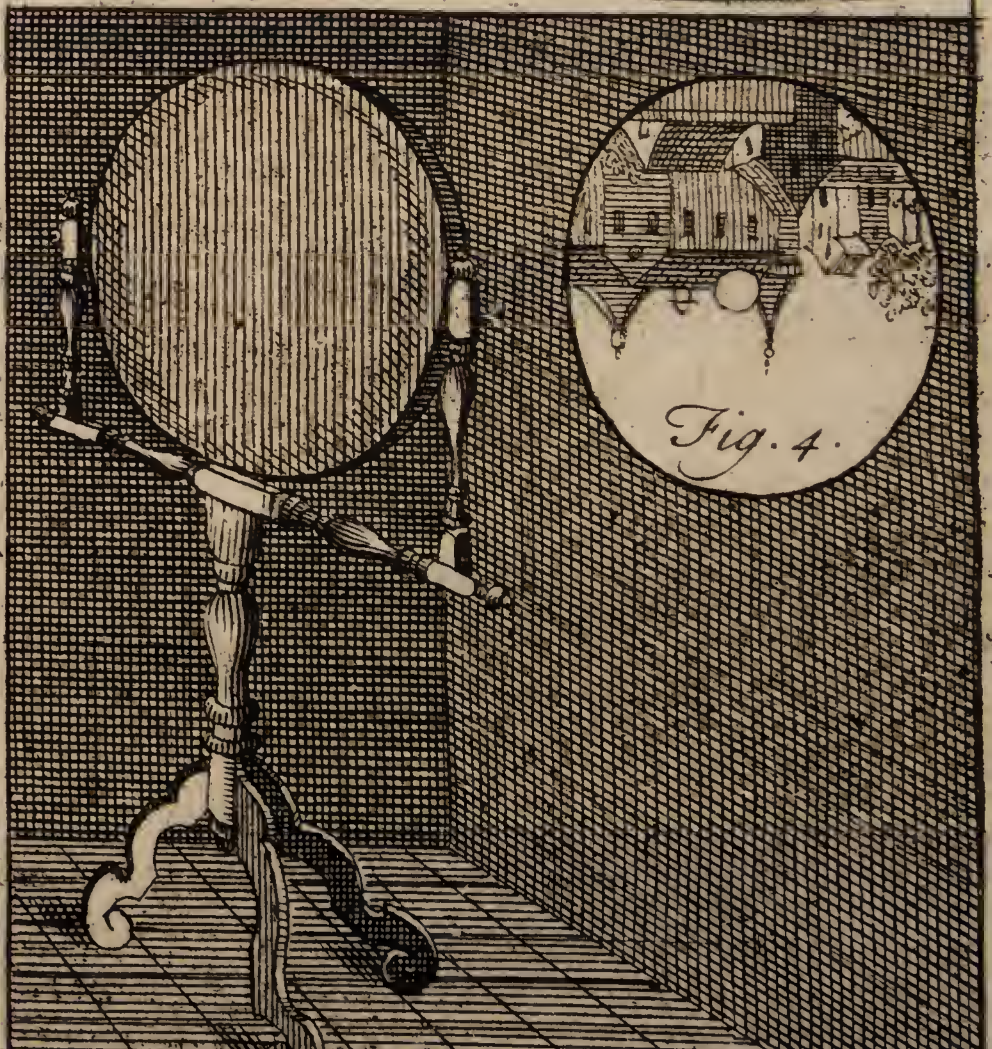


Fig. 4.

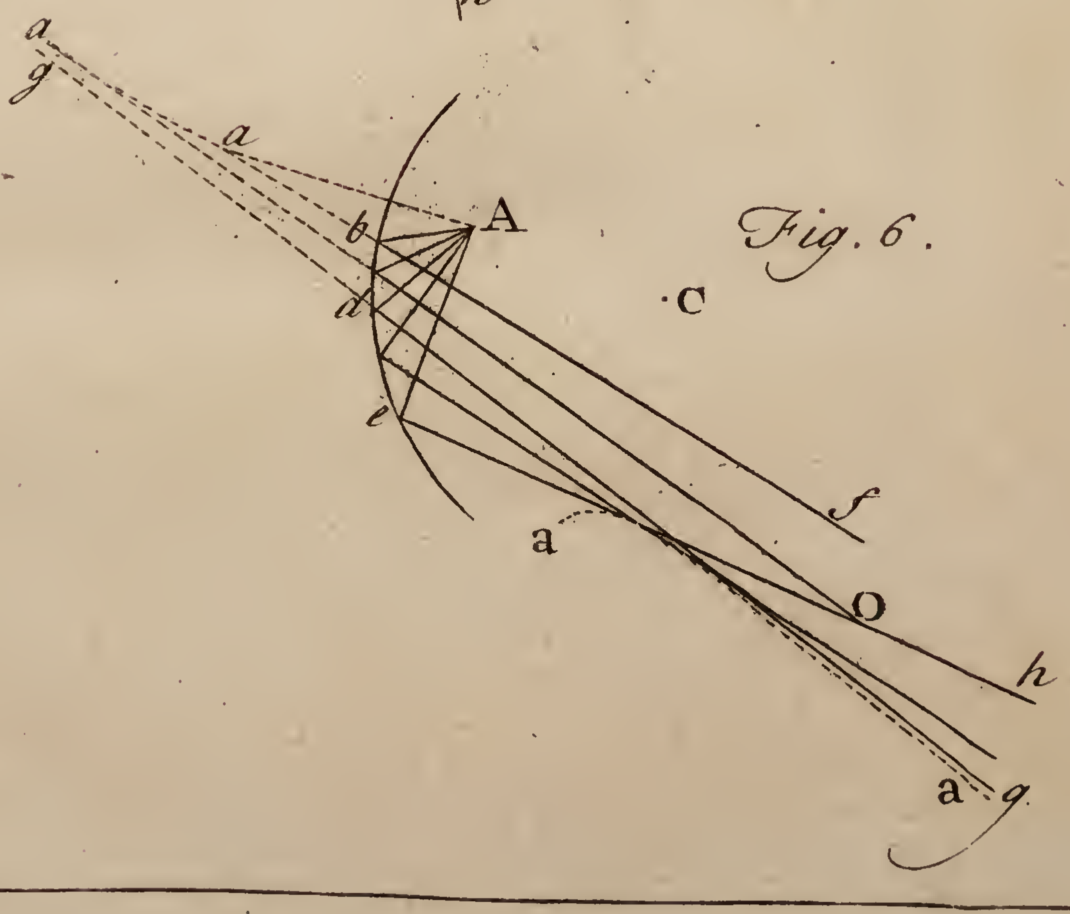


Fig. 6.

a
g
a
b
A
d
C
e
f
a
O
h
a
g

of about 6 Inches Diameter, and from which the Glaſs is diſtant above 6 or 7 Inches; and let this Opening be turn'd from the Light. Now if any Perſon, as A, beholds himſelf at the Diſtance of about 2 Foot from the Glaſs; his Face will appear inverted in the Box towards the Hole; and if the Beholder comes nearer, he will ſee a Head coming out of the Hole.

The Repreſentation of a Point, placed in the Center of a Sphere, coincides with the radiant Point itſelf, and is as it were ſwallowed up by it *. 829

* 821

If the Eye be plac'd in that Center, no Object can be ſeen by it; for then only the Rays that flow from the Eye will be reflected to it *. 830

* 806

If the Object be between the Center and the Point in which parallel Rays are collected after Reflexion, the Object will alſo appear without the Glaſs, at a greater Diſtance from the Glaſs than the Object itſelf *; *the Repreſentation is inverted*, which is proved in the ſame manner as in N° 828; *and magnified*, becauſe it is farther remov'd from the Center, than the Object itſelf is diſtant from it; for the Repreſentation recedes from the Center *in infinitum*, whilſt the Object goes thro' the fourth part of the Diameter of the Sphere. 831

* 822

If the Object be leſs diſtant from the Mirror than the fourth part of the Diameter of the Sphere, according to the different Situation of the Eye, the Object appears either before or behind the Glaſs. 832

Plate XIII. *Fig. 6.*] If the Eye be ſo plac'd, that thoſe Rays may come to it which form the Curve *a a*, as towards *f*, it will ſee the Appearance of the Object towards the Glaſs * magnified; becauſe the Curves, as *a a*, which belong to ſeveral Points, are diverging.

* 824

If thoſe Rays come to the Eye which form the Curve a a, the Object will appear without the Glaſs: And *in both Caſes the Repreſentation is* 833 *erect*; for as the Point A aſcends or deſcends, the Curves *a a* and a a, in which it is repreſented, are agitated with the ſame Motion.

834 *If the Eye be* in the Point, in which the reflected Rays that belong to each Curve interſect one another, *as in* O, *the Appearance of the Object be double.*

It is plain in every Caſe of the Appearance, that the Points have not the ſame Relation to one another, as the Points of the Object; and 835 therefore that a *concave Mirror never repreſents the Object exactly*: But the moſt irregular Repreſentation of all, is that which is in ſuch Lines as a a.

836 There are alſo cylindric Mirrors convex and concave; theſe in one reſpect are Plane, and in another reſpect ſpherical; and therefore the Repreſentation of the Object is very irregular; which Irregularity, ſince it depends upon a regular Figure, may be ſo determin'd, that Pictures may be drawn, which tho' truly irregular, will in ſuch a Glaſs appear regular by Reflection, in a determinate Situation of the Eye.

CHAP. XVI.

Of the Magic Lantern.

THERE are ſeveral Machines made by the Combination of Mirrors and Lenſes, which afford uſeful and pleaſant Appearances; whoſe Explanation may be eaſily deduc'd from what has been ſaid.

Amongſt many other I ſhall only chuſe to explain one, in which Figures that are painted upon ſmall pieces of Glaſs are repreſented monſtrouſly large upon a white Plane. This is a

Phænomenon wonderful enough to deſerve a particular Explanation. The Inſtrument that performs this is call'd a *Magic Lantern*, which Optic Writers have not altogether paſs'd by, but yet have not ſufficiently explain'd.

Plate XIV. *Fig.* 1.] Let there be a wooden Box about a Foot and an half long, 14 Inches high, and as wide; there muſt be a concave Mirror S, of 8 Inches Diameter, and a Portion of a Sphere of 18 Inches: This Mirror is fix'd to a Foot which moves upon Rulers along the Length of the Box. 837

There is alſo in this Box a Lamp L, ſuſtain'd by a wooden Foot which is moveable long-wiſe between two Rulers in the Sides of the Box. The Pipe of the Lamp ſtands forward in ſuch manner, that the Center of the Flame is overagainſt the Center of the Surface of the Mirror; this Flame is made up of four little Flames, which by touching one another, make one ſquare Flame, above two Inches wide.

In the Top, or upper Plane of the Box, there is an oblong Hole, which has a Cover that ſlides in two Grooves, or between two Rulers or Ledges: Thro' this Cover paſſes the Chimney C, which (as you ſee in the third Figure) ſtands up about one half Foot above the Box. The Chimney is moveable with the Cover, whilſt the Opening remains ſhut; that the Chimney may be always over the Lamp.

In one of the little Sides of the Box which is overagainſt the Mirror there muſt be a round Hole about 5 Inches wide; which muſt have in it a Convex Lens of Glaſs of the ſame Bigneſs V, convex on both ſides, which are Portions of a Sphere of one Foot Diameter: The Axis of this Glaſs being continued to the Surface of the Mirror, will be perpendicular to it, and fall upon its Center, as likewiſe to the Plane of the Flame, thro' whoſe middle Point it alſo paſſes.

This Hole is ſhut and open'd by a Plane moveable in a Groove, which is mov'd by a Cylinder that ſtands out of the Box at E.

To this Hole without the Box anſwers the Tube T, whoſe Length and Diameter is of about *6* Inches, at the End of which there is a Ring, in which a ſecond Tube *t* moves, of about 4 Inches Diameter, and 5 or *6* Inches long.

In this leſſer Tube there are two Lenſes; the firſt in that end which is thruſt into the Tube T, and it is of the ſame Convexity as the Glaſs V, and three Inches and a half Diameter. The ſecond Lens is three Inches from the firſt, and flatter, being terminated by Portions of a Sphere of four Foot Diameter. Between theſe Lenſes, at the Diſtance of about one Inch from the ſecond, there is plac'd a wooden circular Stop, or Aperture, which ſhuts up all the Tube, except an Hole of an Inch and a quarter Diameter in the middle of the Wood.

The Objects that are to be repreſented, are to be painted upon a flat thin piece of Glaſs, which muſt be mov'd without the Box over-againſt the Glaſs V, between it and the Tube T, the Picture being in an inverted Poſition. If theſe Pictures are round they may be of 5 Inches Diameter: That they may be moved eaſily, they are put into flat Boards, three in one Board. The Pictures alſo may be painted upon long Glaſſes, which may be ſucceſſively made to ſlide before the Glaſs V.

Plate IV. *Fig.* 3.] This whole Box ſtands upon a Frame or Foot, made ſo that it may be fix'd at different Heights. There are flat pieces of Wood fix'd to the Box, at Bottom, which ſlide in Grooves in the Frame; each of them has a

Slit in it; ſo that the Box may be made faſt at at any deſir'd Height by the help of Screws join'd to the Frame, and moveable in the Slits.

The whole Machine is plac'd at the Diſtance of 15, 20, or 30 Feet from a white Plane, which Diſtance muſt be different according to the Bigneſs of the Plane; for this Diſtance may be equal to the length of the Plane: The Box muſt be juſt at ſuch an Height that the Tubes, in the ſide of the Box, may be exactly poſite to the middle of the Plane.

The Lamp being lighted, the Box muſt be ſhut, and the Figures which are painted upon the Glaſs will be repreſented upon a white Plane. By moving backwards and forwards the Tube that has the two Lenſes in it, you will find the proper Poſition of the Glaſſes requir'd to give a diſtinct Repreſentation. As for the Diſpoſition of the ſeveral Parts of the Machine which immediately ſerve for exhibiting this Appearance, we ſhall here more particularly explain.

Plate XIV. *Fig.* 2.] The Parts in this *Figure* are ſhewn ſeparately; S S is the Mirror, *l l* the Flame which conſiſts of four Flames in the Line *l l*; V V is the Glaſs V of the firſt Figure; O O is a Picture painted upon a flat thin piece of Glaſs; *a a* the biggeſt Lens; *d d* the flatteſt Lens; *b b* the wooden Stop between the Lenſes; *f* the Aperture or Hole in the middle of the wooden Circle. 838

These Things being diſpos'd as has been already explain'd, and as may be ſeen in the Figure, the Rays which proceed from a Point of the Picture O O, by going thro' the Lens *a a*, become leſs diverging, and fall upon the Lens *d d*, as if they came from a Point more remote *; from this Lens they go out more converging *, and are collected upon the Surface of the white

* 699

* 699

Plane, where they exhibit the Point of the Picture that is painted on the Glaſs *. This Picture is illuminated both by the Rays that proceed from the Flame *l l*, and by the Rays reflected by the Mirror S S. *711

839 For the Perfection of this Machine it is requir'd, *1ſt*, That the Figure O O be enlighten'd as much as poſſible; *2dly*, That it be equally enlighten'd in all its Points; *3dly*, That all the Light by which every Point of the Picture is enlighten'd, go thro' the Lenſes *a a* and *d d* to the white Plane, and ſerve to make the Repreſentation; *4thly*, That no other Light but that go out of the Box, leſt the Repreſentation ſhou'd be leſs lively, by reaſon of extraneous Light.

The firſt Requiſite depends upon the bigneſs of the Flame and of the Mirror, and of its Concavity; the more concave it is, the nearer it is to be brought to the Flame, and then the more Rays will be intercepted and reflected; yet Care muſt be taken that the Mirror (which may be made of very good Glaſs) be not too much heated.

When the Flame and Mirror are ſo contriv'd, that the Picture is the moſt enlighten'd that it can poſſibly be, and every where equally enlighten'd, the Flame and Mirror muſt be ſo plac'd, that the inverted Image of the Flame ſhall fall juſt upon the Picture *. Now as the *826 Repreſentation of the Flame can be encreas'd and diminiſh'd *, the Mirror and Flame muſt *826 be ſo diſpos'd, that the Repreſentation of the Flame ſhall cover the whole Picture upon the Glaſs, but ſo as not to exceed it: For then the Picture is as much enlighten'd by the reflected Light as it can be, and all its Points are equally illuminated; the direct Light alſo does pretty near equally fall upon all the Points of the Picture; this Light wou'd indeed be encreas'd by bringing the Flame nearer; but the reflected Light wou'd be diminiſh'd, and the Diminution of this laſt wou'd be greater than the Encreaſe of the other.

The Glaſs V V ſerves to inflect the Light, by which the Picture O O is illuminated, before it comes to the Picture; by which Inflection all the Light comes to the Lens *a a*, and ſerves for the Repreſentation on the white Plane.

All the Light that is of Uſe for this Repreſentation, goes thro' the Hole *f*; and the Rays coming from different Points, interſect one another there; wherefore the Picture upon the Glaſs which is placed inverted, is repreſented erect upon the white Plane; by the Ring *b b* all the Rays which do not ſerve to form the Repreſentation, are intercepted, leſt they ſhou'd enter the Room, and make the Picture leſs diſtinct. This Ring or Aperture alſo intercepts thoſe Rays by which one Point is more enlighten'd than another, whereby the Light, which (from what has been ſaid) is equally enough diffus'd, is yet made more equal. But unleſs the Stop or Aperture *b b* be juſt where the Rays interſect, it does a great deal of Miſchief.

BOOK III.

PART III.

Of Opacity and Colours.

CHAP. XVII.
Of the Opacity of Bodies.

DEFINITION.

840 BODIES *that tranſmit the Light are*
*615 *call'd* Tranſparent. Such are all Mediums *, except a *Vacuum.*

841 *There is no Body whoſe ſmalleſt Parts are not tranſparent:* No one who is uſed to Microſcopes will doubt of this. There are ſome Parts of Metals, which though very ſmall, do not tranſmit the Light: But if they be diſſolv'd in *Menſtruums*; that is, if they be divided into much leſs Parts, they become tranſparent. One may alſo prove by a very eaſy Experiment, that Light can go thro' ſeveral opaque Bodies.

Experi-

Plate 14

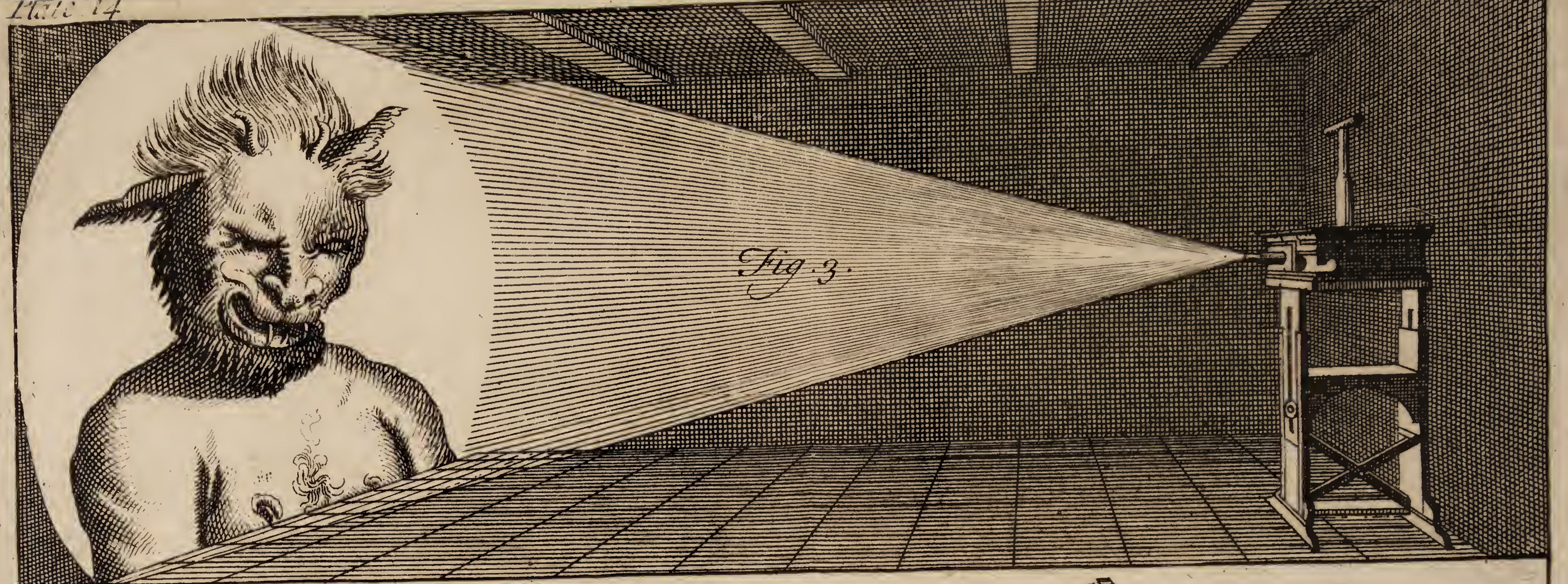
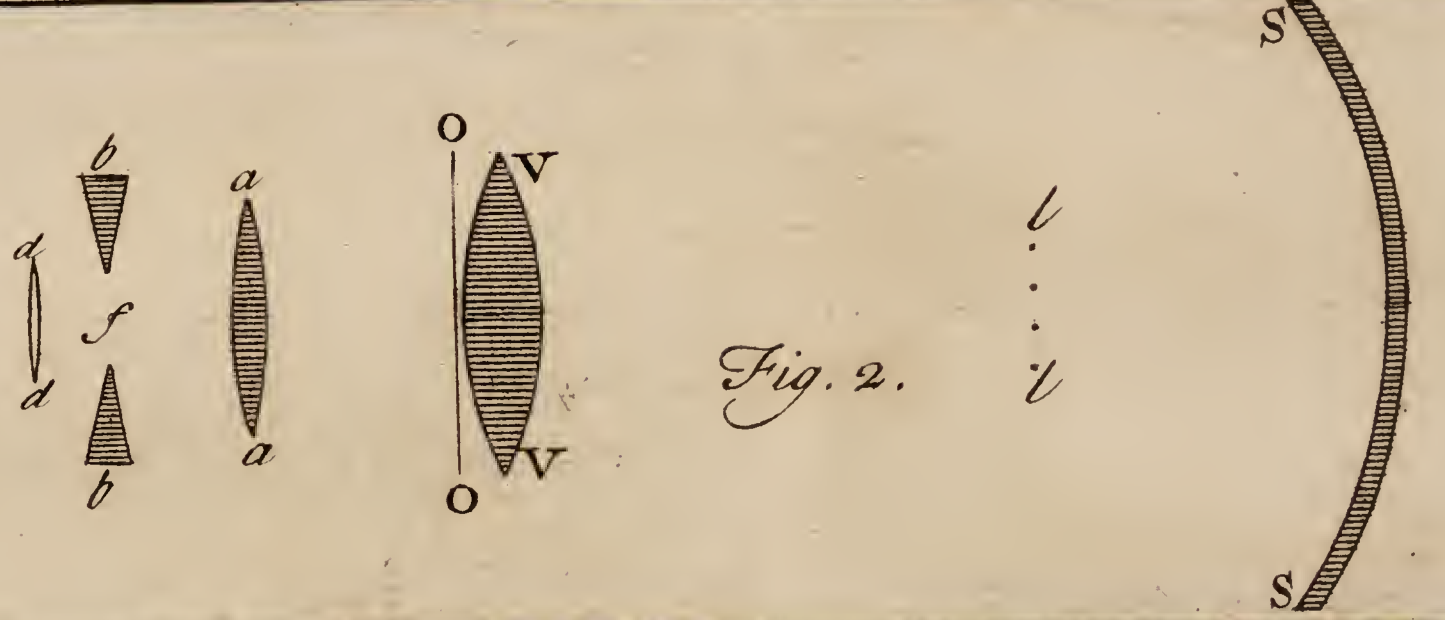


Fig. 3.


b
d
f
d
b
a
a
O
V
V
O
l
l
S
S
Fig. 2.

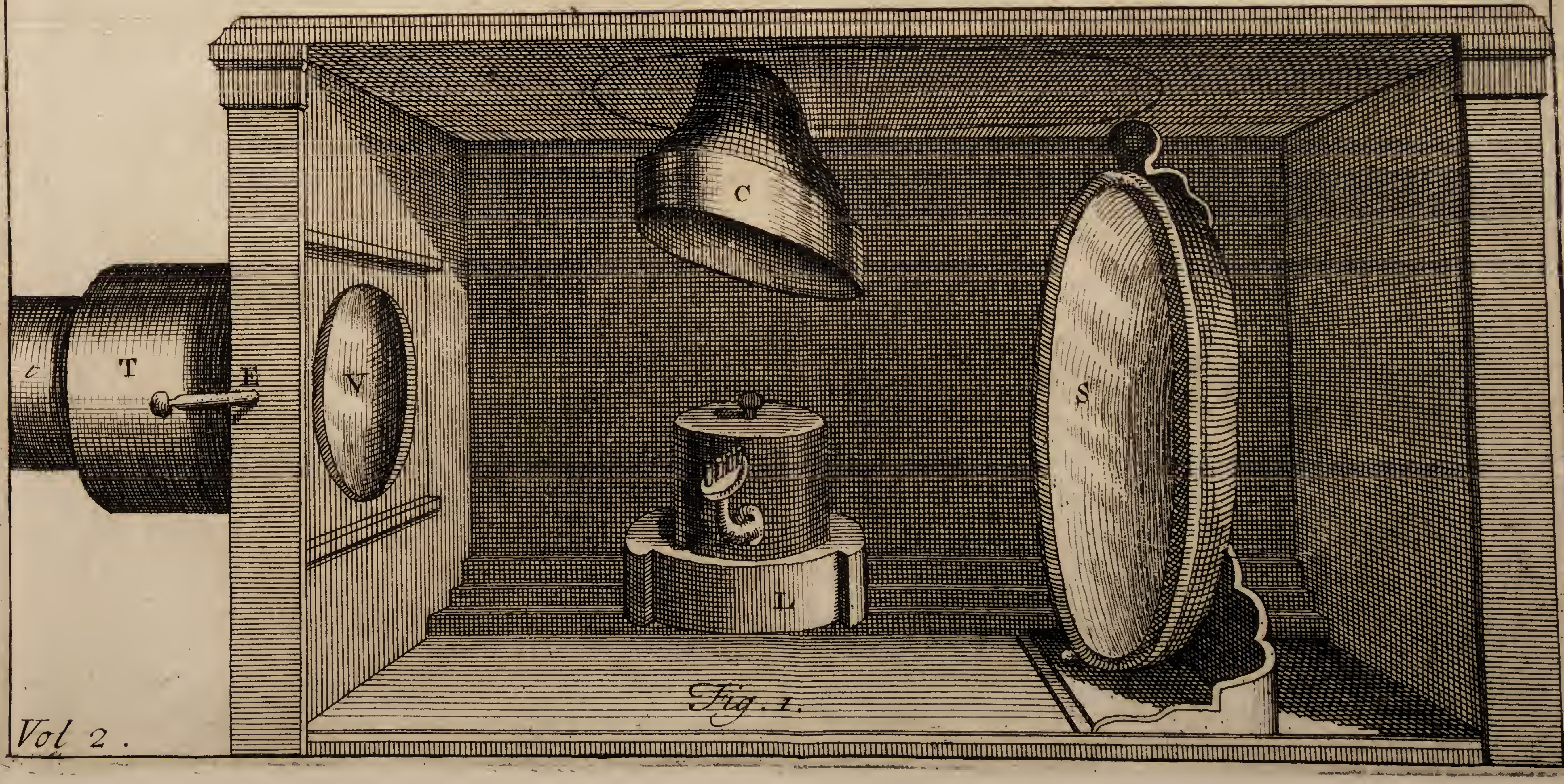


Fig. 1.

Vol 2.

Experiment 1.] In a dark Room, in which the Sun's Light comes in thro' an Hole, let that Hole be cover'd with a thin Plate of an opaque Body, and the Light will go thro' it; a piece of Wood of the Thickneſs of the tenth part of an Inch, does not intercept all the Light. But the perfect Tranſparency of Parts in opaque Bodies is not prov'd by this Experiment, for that Tranſparency is only in very ſmall Parts.

842 *Opacity does not* (as is commonly imagin'd) *happen in Bodies, becauſe the Way thro' which the Light might paſs, is ſtopp'd by Particles of Matter;* for Light paſſes thro' all the ſmalleſt Parts of Bodies; neither is ſuch an Interception of Light of any Uſe to cauſe Opacity: It is requir'd for Opacity that the Light ſhou'd be reflected and deflected from a right Line, for which there is only requir'd the Separation of two Mediums *. * 631, 796

Let us conceive a Body conſiſting of very ſmall Parts perfectly tranſparent (ſuch as are the Particles of which Bodies conſiſt *) and ſeparated from one another by Pores; and that thoſe Interſtices are either void, or fill'd with a Medium whoſe Denſity is different from that of the Particles; if Light enters ſuch a Body, it will every Moment fall upon a Surface dividing Mediums differing in Denſity; therefore it will undergo innumerable Reflexions and Refractions in that Body *, ſo as not to be able to get thro' it. Therefore we ſee that *Opacity depends upon the Pores*; for *if you fill the Pores with a Medium of the ſame Denſity as the Particles of the Bodies themſelves*, the Light will undergo no Reflexion or Refraction in the Body, but paſs directly thro' *; and *the Body will be tranſparent.* 843

* 841

* 631, 796

* 841, 631, 796

Tho' we cannot make Experiments whereby to fill the Pores of a Body with a Medium exactly of the ſame Denſity as the Particles, yet the following Experiments will clearly enough prove Sir *Iſaac Newton*'s Doctrine concerning Opacity.

Experiment 2.] Paper becomes more tranſparent when moiſten'd with Water; for it fills the Pores, and differs leſs in Denſity from the Particles than Air does. Oil has the ſame Effect.

Experiment 3.] Take a piece of Glaſs two Inches thick; and take ſeveral Plates of the ſame ſort of Glaſs laid upon one another, yet ſo as not to be quite two Inches thick; and you will find that theſe will be leſs tranſparent than the ſolid piece, becauſe of the Air between the Plates, which does not get into the ſolid Piece where all the Parts cohere.

Experiment 4] Take twelve Plates of the ſame Glaſs, as near as may be of the ſame Thickneſs; let ſix and ſix of them be laid together; if you take the leaſt tranſparent of thoſe two Parcels, and having dipp'd it in Water, take it out again, it will become more tranſparent than the other; becauſe the Water, which in that Caſe fills the Interſtices between the Planes, differs leſs in Denſity from the Glaſs than Air does.

What has been ſaid of Opacity is farther confirm'd, and put out of all doubt by innumerable
844 Experiments, by which *Bodies perfectly tranſparent become opaque, by the Separation of their Parts,* without the Intervention of any opaque Body.

Experiment 5.] Let any perfectly tranſparent Liquid, that may be chang'd into Froth, be ſhak'd, till it be full of Bubbles; it will immediately become opaque, by reaſon of the Interſtices that are fill'd with Air.

Experiment 6.] Turpentine and Water are tranſparent Bodies, but when mix'd, they become opaque.

Experiment 7.] Water and Oil by being mix'd together become opaque, tho' ſingly they are tranſparent.

Experiment 8.] Tho' Glaſs be tranſparent, yet if it be reduc'd to Powder it becomes opaque; as it alſo does when crack'd.

We clearly ſee in all theſe Caſes that Opacity is produc'd, becauſe there is a Medium of different Denſity between the tranſparent Parts; which may alſo be obſerv'd in the Clouds, which are opaque on account of the Air interpos'd between the Particles of the Water.

If we add to this, what is ſaid in the 22d Chapter following, concerning the Colours of thin Plates, we ſhall have new Experiments, by which alone it is fully prov'd that Bodies intercept the Light, becauſe they conſiſt of very thin Particles, encompaſs'd with a Medium differing from them in Denſity.

Some opaque Bodies reflect a little Light, and the reſt of the Light, by innumerable Diviſions which it undergoes in the Reflexions and Refractions above-mention'd, is extinguiſh'd in the Body; ſuch are black *Bodies*; if there were any Bodies *perfectly black*, they *wou'd reflect no* 845
Light; for all Bodies, when no Light fall upon them,

them, and therefore they reflect no Rays, appear black.

Other opaque Bodies appear to have various Colours; ſome tranſparent Bodies are alſo ting'd Colours: And whence thoſe ariſe we are now to examine.

CHAP. XVIII.

Concerning the different Refrangibility of the Sun's Rays.

BODIES appear differently colour'd, tho' they be enlighten'd by the ſame Rays of the Sun which are reflected by them. Beſides theſe there are ſeveral Phænomena of Light, relating to Colours, not to be overlook'd.

846 In theſe we are to obſerve three Things. 1*ſt*, The Rays are to be examin'd. 2*dly*, Their Reflexion is to be obſerv'd. 3*dly*, We are to enquire into the Conſtitution of the Surfaces of Bodies differently colour'd.

847 As to the Rays, the firſt Property to be taken Notice of here, is, that *in the ſame Circumſtances all ſorts of Rays do not undergo the ſame Refraction.*

DEFINITION I.

848 *The Rays which undergo this different Refraction, are ſaid to have a* different Refrangibility, and *thoſe are ſaid to be* moſt refrangible, *which are moſt inflected by Refraction.*

DEFINITION II.

849 *Thoſe Rays are ſaid to be* Homogeneous, *which do not differ from one another in Refrangibility.*

DEFINITION III.

And thoſe are call'd Heterogeneous, *which, under the ſame Circumſtances, are not equally inflected by Refraction.* 850

Plate XV. *Fig.* 1.] Between AB and CD let there be a Sun Beam made up of an innumerable Quantity of parallel Rays; theſe are not equally refracted; for if they fall obliquely on the Surface BD of the denſer Medium, ſome of them are refracted between BE and DG, and are mov'd according to that Direction in the denſer Medium; others are more inflected, and direct their Motion between BF and DH according to the Direction of thoſe Lines; and indeed no Direction can be conceiv'd between the Mediums along which the Rays do not move in every Point between B and D: So that the leaſt Beam whatever is, by Refraction, divided into an innumerable Quantity of Rays; becauſe every Sun-Beam, however ſmall, is heterogenous, and conſiſts of an innumerable Quantity of Rays refrangible in all Degrees of Refrangibility.

851 The above-mention'd parallel Rays falling upon a plane Surface, by Refraction are mov'd between BE and DH; which Lines diverge from each other, and being continued, are more and more ſeparated; ſo that the Rays above-mention'd are diſpers'd by Refraction. In N° 653. *we have conſider'd the Rays as homogeneal,* as alſo every where *in the foregoing Part*; the Difference of Refrangibility is ſmall enough in the Rays of the Sun, not to have been worth obſerving in the foregoing Propoſitions. Beſides, we were firſt to examine what happens in homogeneal Rays; and what muſt be chang'd in the Propoſitions, upon account of the different Refrangibility, will eaſily appear.

That

852 That this Refrangibility of the Rays may be made viſible, the above-mention'd Divergence muſt be encreas'd; which will be perform'd, if the Rays above-mention'd fall upon the Surface E H, which terminates a denſer Medium, and ſeparates it from the rarer Medium, and which makes any Angle with the Surface B D, and is ſo inclin'd to it, that the Rays which are more refrangible, fall more obliquely upon it than thoſe that are leſs refrangible; ſo that the former going into a rarer Medium are more turn'd out of the way, and diverge more from the others upon a double account, that is, both upon the account of a greater Refrangibility and of a greater Inclination. The Rays between B E and D G, which are the leaſt refrangible, being refracted a ſecond time, continue their Motion between E I and G L, others between F M and H N: In which Caſe, if theſe Rays fall upon a Plane at the Diſtance of 15 or 20 Foot, thoſe that are moſt refrangible will be ſeparated from thoſe that are leaſt refrangible, and the whole intermediate Space is enlighten'd with Rays endow'd with a mean Refrangibility.

Experiment 1. *Plate* XV. *Fig.* 2.] Let there be an Hole in the Plate of Metal in the Window-ſhut, of about a quarter of an Inch, thro' which a Sun-Beam enters the darken'd Room: Let this Beam fall upon a triangular Priſm of Glaſs A A, in ſuch manner, that it may be wholly reflected by the lower Surface (ſee the *Exper.* of N° 789.) By the two Refractions which the Light undergoes, Rays that are differently refrangible do not diverge, and being reflected, come upon a ſecond Priſm B B, which is likewiſe of Glaſs, and triangular, in the ſame manner as if they had come directly from the Sun.

Theſe two Priſms are moveable about their Axes, as was before explain'd*; the firſt A A is laid upon a piece of Wood faſten'd to it, yet ſo as not to hinder it from turning about its Axis; this piece of Wood is faſten'd to a Three-legg'd Staff with a Ball and Socket, ſuch as is us'd in practical Geometry. The ſecond Priſm B B is laid on a Frame or Stand S, in whoſe oppoſite Sides there are ſeveral Slits that anſwer one another; by theſe the Priſm is ſuſtain'd at different Heights, but always horizontally, the End of the Axis being plac'd in correſpondent Slits.

* 791

The Light that comes to the Priſm B B moves perpendicular to its Axis, and paſſes thro', as is demonſtrated in *Fig.* 1. in which B D and E H repreſent the Sides of the Priſm; the Light is alſo equally inclin'd to each Side; which will happen by moving the Priſm about its Axis; for the Light of the Sun (as you move the Priſm) will aſcend, and then deſcend again; and the Situation requir'd is that in which the Light is higheſt of all: Now both the Priſms are to be ſo diſpos'd, that in this Caſe the Light may go horizontally out of the Priſm B B. This horizontal Beam, at the Diſtance of 15 or 20 Foot, muſt fall upon the Board T which is cover'd with white Paper, and has ſuch a Foot, that upon it, it may be rais'd and fix'd at different Heights. The Rays come diverging to the Paper, and upon it form the Oblong Image RV, terminated at the Sides by parallel Lines, but ſemicircular at R and V.

If the Rays of the Sun that go thro' the round Hole fall upon a Plane at a certain Diſtance, they will form a bright round Spot, ſo much the greater, as the Plane is more diſtant from the Hole; which ariſes from the Rays that come from the Sides of the Sun, which making an Angle with thoſe that come from its Center to the Hole, and interſecting them in the Hole, gives the Image of the Sun upon the Plane.

If the Rays did not go thro' the Priſm B B, and fall upon a Plane at the Diſtance of the Board T, the Image of the Sun wou'd have its Diameter equal to the Breadth of the Image V R; which Breadth is not alter'd by the Refraction, becauſe the Rays enter the Priſm perpendicular to its Axis, and in reſpect of the Breadth of the Image, are not inclin'd to it. But as in another reſpect the Image of the Sun is *oblong*, it follows plainly from thence, that all the Rays have not undergone the ſame Refraction; for homogeneous Rays, tho' refracted, will give a round *Image of the Sun.* The leaſt refrangible Rays go to R, and the moſt refrangible to V; and the whole Image R V is terminated with Semicircles at R and V, becauſe the whole Image *conſiſts of Circular Images.* Now between R and V there are innumerable Quantities of circular Images, made by Rays of all poſſible Refrangibilities; otherwiſe the Image R V wou'd not be terminated with rectilinear Sides.

854 In moſt Experiments, we have ſaid that the Light is let into the darkened Room thro' a Slit or an Hole, which we leave to the Contrivance of the Workman; our Method was the following.

Plate XV. *Fig.* 3.] We made an Hole 4 Inches ſquare in the Window-ſhut, which on three Sides had Ledges of Wood A B, B C, C D, ſo rabbetted, as to make Grooves to keep in the ſquare flat piece of Wood QL, which is ſix Inches long, and ſix Inches wide. It may be drawn out, and ſeveral Sorts of them ſerve for ſeveral Experiments. That which we uſe in the following *Experiment* has a Hollow and a Hole in the middle behind to contain a convex Lens, which is the Object Glaſs of a Teleſcope of 16 or 20 Foot; the round Hole in the middle mark'd *f* is above half an Inch in Diameter, thro' which the Rays of the Sun paſſing thro' the Glaſs, enter the Room. In the Fore-part alſo the Board C is hollow'd, but not in the middle; this Hollow contains the braſs round Plate L, which towards its Circumference has an Hole at *f*, which Hole is equal to the Hole in the Board Q itſelf, and agrees with it. Together with L there is another concentric Plate, which is leſs, and moveable about the Center; this Plate has ſeveral unequal Holes, which ſucceſſively comes to *f* as the *Plate* is turn'd round; ſo that you may at Pleaſure let the Light enter a dark Place thro' a bigger or a leſſer Hole; which in many Experiments, that are made without the Lens above-mention'd, is of good Uſe. The Pin *m* join'd with the Plate ſerves to turn it by.

Experiment 2.] Let in a Sun-Beam thro' the Lens above-mention'd, thro' an Hole a quarter of an Inch wide, into the darken'd Room; by the Rays thus let in, at the Diſtance where parallel Rays are collected, the Sun is very exactly repreſented, and its Image terminated with exactly deſcrib'd Bounds. For the Rays that come from the ſeveral Points of the Sun, which by reaſon of its immenſe Diſtance, may be look'd upon as parallel, are collected in one Point at that Diſtance.

Plate XV. *Fig.* 2.] Now if with theſe Rays you make the Experiment above-mention'd, the ſeveral Images made by the homogeneal Rays, ſuppoſing the Board at a juſt Diſtance, are exactly terminated; and therefore the Oblong Image R V, which is made of all theſe Images, is likewiſe regularly terminated.

This Experiment will ſucceed in the ſame manner, if the Rays paſs thro' a Priſm made of any Body which is denſer than Air.

Experiment 3. *Plate* XV. *Fig.* 2.] Let a triangular Priſm be made of Wood and two glaſs Planes, and fill'd with Water; ſuch as is repreſented at B B (*Plate* XVII. *Fig.* 3.) If you make uſe of this Machine inſtead of the Priſm B B in this *Fig.* the Experiment will ſucceed in the ſame manner; and in paſſing thro' Water, heterogeneous Rays in the ſame manner are ſeparated by Refractions.

Experiment 4.] If any Perſon ſtanding 15 or 20 Foot off looks at the Hole thro' which the Light is let in, it will appear round; but if before his Eyes he holds a triangular glaſs Priſm, or the watery one mention'd in the laſt Experiment, ſo that the Rays coming from the Hole (after ſuch Refractions as the Light ſuffers in the foregoing Experiment) reach the Eyes, the Hole will appear oblong. The Situation of the Priſm will be found, if holding it horizontally with one Edge (or the refracting Angle) upwards, it be a little mov'd about its Axis, ſo as to make the Image of the Hole to aſcend and deſcend; and the Priſm be held faſt in that Poſition in which the Hole appears moſt depreſs'd.

This Experiment, as well as the foregoing ones, proves the different Refrangibility of the Rays; for by the homogeneal Rays of each Refraction, the Hole appears in the imaginary Foci of the Rays coming from the ſeveral Points of the Hole *, which Image is round; the Rays which undergo a different Refraction, enter the Eyes in different Directions; and you have ſeveral Images, all which form the oblong Image, which is really ſeen. * 737

855 But that *this different Refrangibility does not depend upon the refracting Medium, but the different Conſtitution of the Rays themſelves* is prov'd, becauſe thoſe Rays which in one Caſe undergo the greateſt Refraction, are in any Refraction turn'd out of the Way more than any.

Experiment 5. *Plate* XV. *Fig.* 4.] All Things being diſpos'd as in the firſt Experiment at any Diſtance from the Priſm BB; let the oblong Image of the Sun fall upon the Vertical Priſm CC, which is alſo moveable about its Axis; as the Rays go thro' it, let it be turn'd about its Axis, and left fix'd where the Rays are leaſt of all turn'd out of the Way by Refraction thro' the Priſm: In that Caſe the Rays are refracted in the ſame manner thro' this Priſm as thro' the firſt, but they are not diſpos'd the ſame way, for that wou'd form a ſquare Image. But here the Image keeping the ſame Breadth is inclin'd at RV, the Rays at V being moſtly turn'd out of the Way, as in the Refraction thro' the firſt Priſm BB.

856 *The Demonſtration*, before given *, *of the conſtant and ſettled Ratio between the Sines of the Angles of Incidence and Refraction, may be referr'd to any homogeneous Rays*; but conſidering the different Refrangibility of the Rays, this Proportion varies, as it follows from the Experiments of this Chapter. * 639

857 But *the Refrangibility in all the different Sorts of Rays is every way unchangeable*, as will appear by the Experiments to be mention'd hereafter.

CHAP. XIX.

Concerning the Colours of the Rays, and their Unchangeableneſs.

858 *THE different Refrangibility of the Rays goes along with the different Colours; and every ſort of Rays as they are more or leſs inflected by Refraction, have a particular Colour of their own, and which is wholly unchangeable.*

In reſpect of the Colours, the ſame Thing is to be obſerv'd as has been taken Notice of in regard to other Senſations *; the Colours are Idea's which have nothing common with the Rays, by which they are excited: Therefore we muſt define what we mean by colour'd Rays and colour'd Objects.

* 502, 580 716

DEFINITION I.

859 *An Object is ſaid to be of ſuch a Colour, whoſe Idea is excited in the Mind by the Rays reflected from the Object.*

DEFINITION II.

860 *Homogeneous Rays, which ſtriking upon the Retina, excite in our Mind an Idea of any Colour, are call'd Rays of that Colour.*

We have ſaid that the Rays excite an Idea, by which we underſtand that the Rays put the Fibres into a trembling Motion, and that Motion occaſions an Idea in the Mind.

Plate XVI. *Fig.* 1.] It is very evident from the Experiments of the foregoing Chapter, that Rays of a different Refrangibility have a different Colour; for thoſe Experiments ſhew that the Image of the Sun, which is oblong, is tinged

Plate 15. front page. 116.

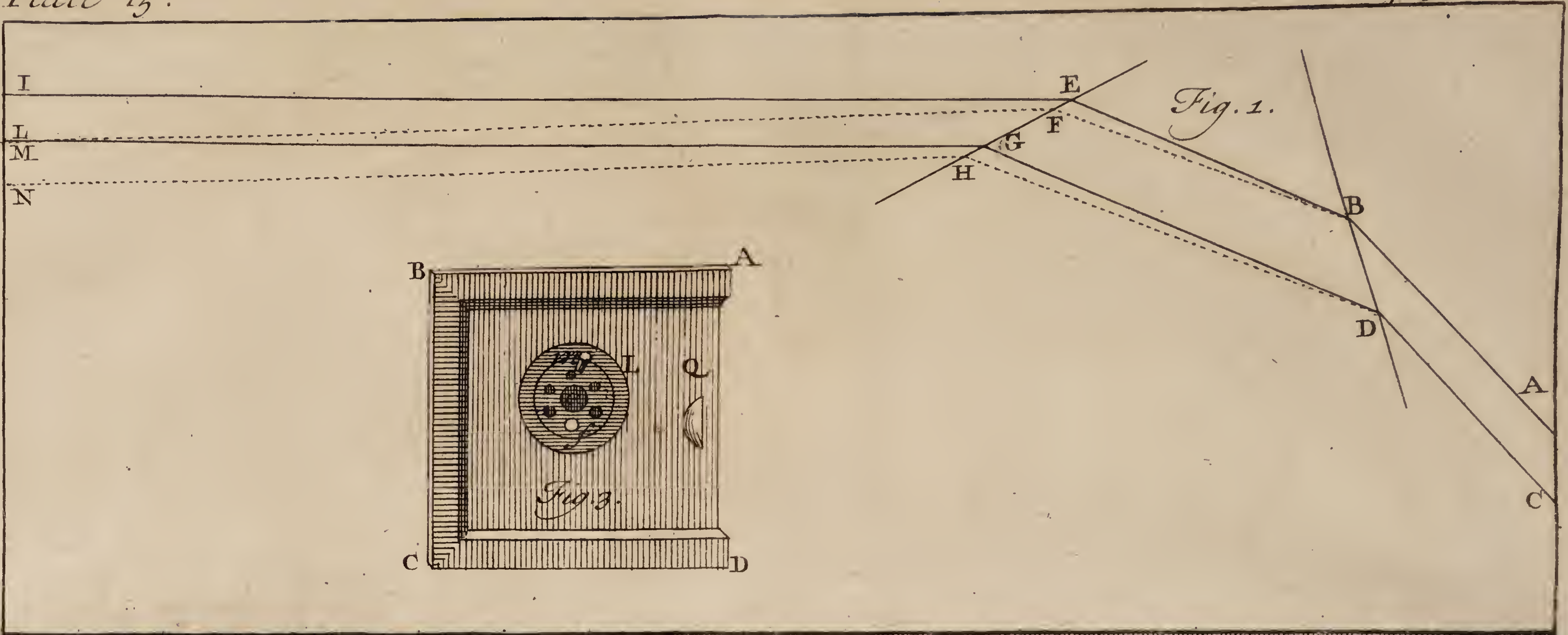

I
L
M
N
E
F
G
H
B
D
A
C
B
A
L
Q
C
D

Fig. 1.

Fig. 3.

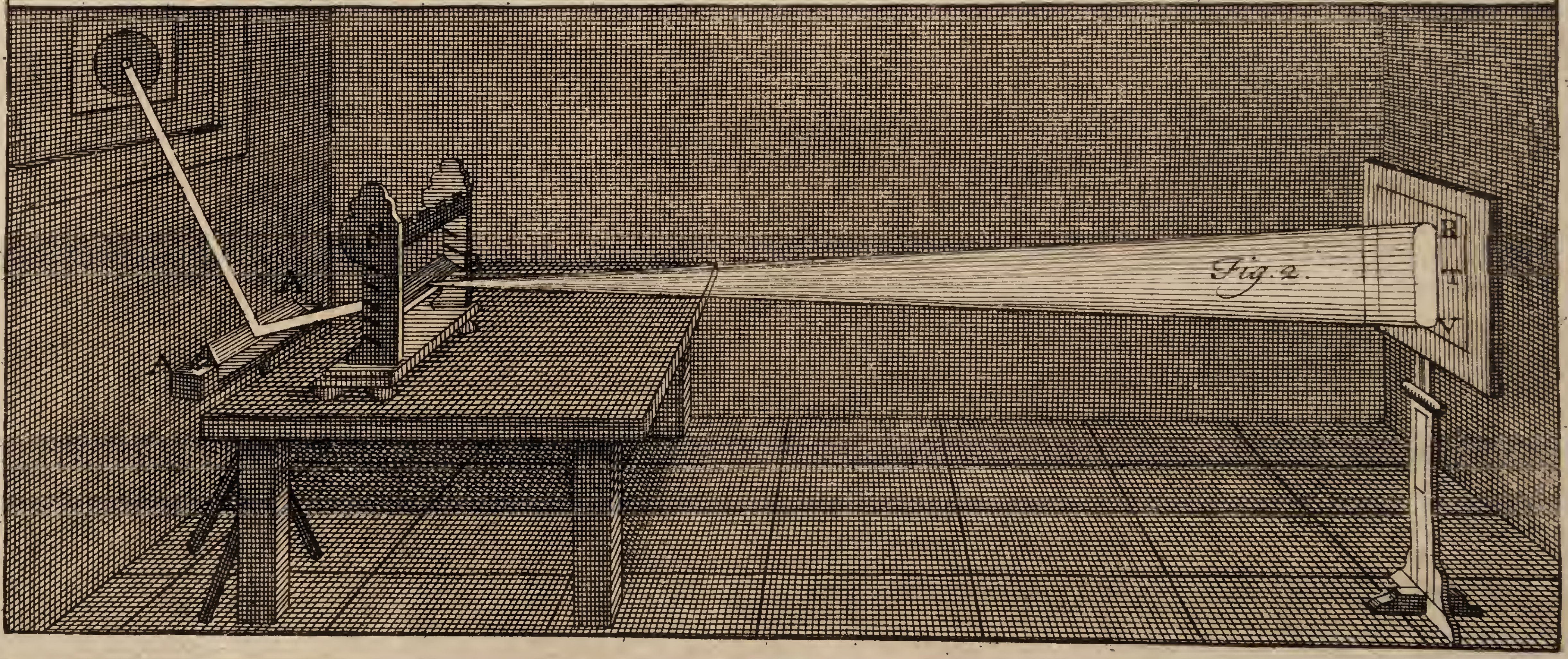


Fig. 2.

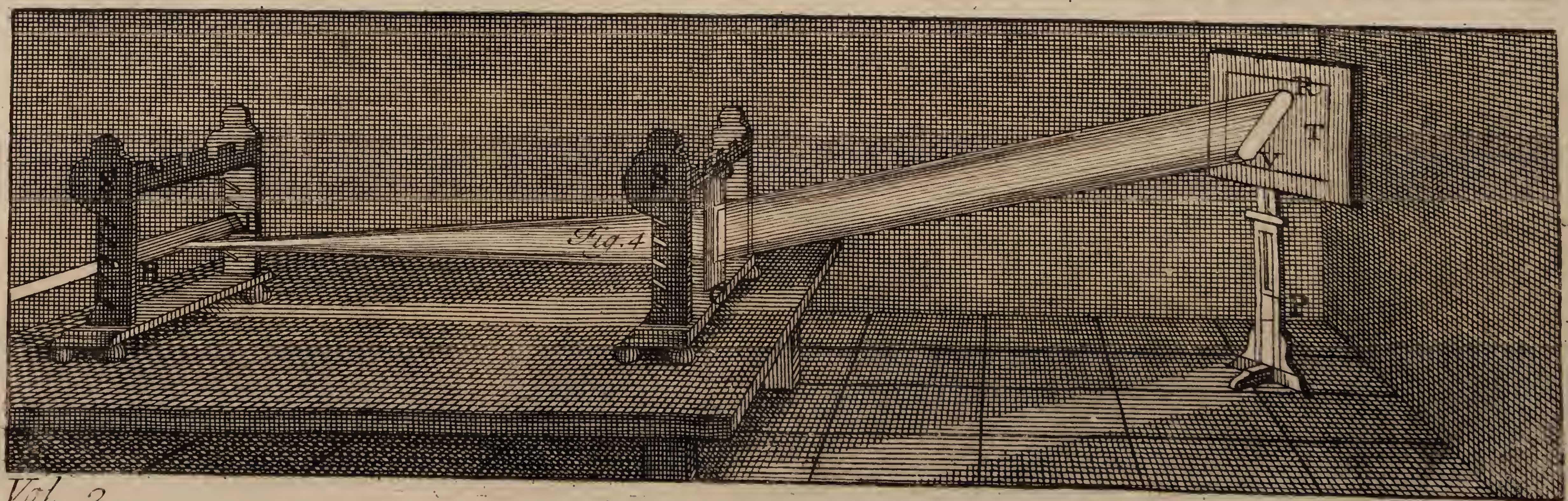


Fig. 4.

Vol 2.

tinged with different Colours. *The Rays which are leaſt turn'd out of the way by Refraction, are red; the reſt of the Colours are in the following Order, namely Orange, Yellow, Green, Blue, Purple and Violet,* of which laſt Colour are the Rays that are moſt refracted *. The oblong Image of the Sun above-mention'd, as has been ſaid *, is made up of an innumerable Quantity of round Images; if their Diameters be diminiſh'd (which is done by intercepting the Sun's Rays, ſo that only thoſe that come from the Center of the Sun ſhall paſs thro' the Priſm) the Centers of the particular Images which make up the oblong Image will not be chang'd; and therefore the Length of the Image *a h*, between parallel Lines, is not chang'd: And this alone wou'd remain the ſame, if the Breadth of the Image ſhou'd be infinitely diminiſh'd: And therefore this Length alone is to be conſider'd in determining the Limits of the Colours in the Image itſelf; theſe Colours are repreſented in this Figure by the Letters *a, b, c, d, e, f, g, h,* and the Number which is ſet down againſt each Colour denotes the Space taken up by it in the Image, the whole Length of the Image being divided into 360 Parts. 861 * 853

If the Breadth of the oblong Image of the Sun be diminiſh'd, the heterogeneous Colours are more ſeparated in the Image; becauſe there are fewer particular Images confounded in the ſeveral Points, where Rays of different Refrangibilities differ little from each other. 862

The Colour of any Ray, as alſo its Refrangibility, cannot be changed by any Refractions, or Reflexions, or mingling of the Rays together. 863

In this Chapter I ſhall ſpeak of Reflexion and Refraction, and of the Mixture of Rays in the following one.

864 That the Refrangibility is not chang'd by Refraction, is prov'd by the 5*th* Experiment of the foregoing Chapter; which may alſo be referr'd to Colour; but is more clearly evinc'd by the following Experiment. Concerning which it is to be obſerv'd (as may be alſo ſaid of what follows) that the Experiments are to be made with Priſms of clear Glaſs, free from Veins; for they occaſion the Light to move irregularly; and the Rays are not duly ſeparated by the Refractions.

Experiment 1. *Plate* XVI. *Fig.* 2.] Every thing being as in the firſt Experiment of the foregoing Chapter, you muſt make the Experiment with a Sun-Beam, going thro' an Hole of half an Inch Diameter: The Frame or Stand S in which the Priſm is, muſt be ſuch, that the little flat Board *t*, to be us'd in this Eperiment, may move between its ſides; this Board has an Hole F of $\frac{1}{8}$ of an Inch bore, thro' which the Light refracted by the Priſm is tranſmitted, whereby the Rays in the oblong Image are better ſeparated from one another, the Rays being moſtly intercepted; this oblong Image R V, at the Diſtance of 10 or 12 Feet from the Priſm, falls upon the Board *t* of a Stand like the former; in which Board alſo there is a ſmall Hole F like that in the firſt; thro' this the Rays paſs upon a ſecond Priſm laid upon this Stand, and are refracted in the ſame manner as in the firſt. By moving the firſt Priſm a little about its Axis, the Image RV aſcends or deſcends, whereby the different Rays are ſucceſſively tranſmitted thro' the Hole; in every Caſe, the Rays refracted thro' the ſecond Priſm, and ſtriking upon the flat Board T which is cover'd with white Paper, are not diſpers'd at H; but the Image is round, if the Rays fall perpendicularly upon the Paper, and alſo of the ſame

Colour as the Rays falling upon the ſecond Priſm. Yet the Image H is ſo much the more lifted up, as the Rays, by Refraction thro' the firſt Priſm, are more turn'd out of the way; that is, thoſe that are moſt refrangible in the one Caſe, do alſo ſuffer the greateſt Refraction in the other.

It will appear alſo by the following Experiments, that the Refrangibility and Colour are not chang'd by Reflexion. 865

Experiment 2.] The Rays, which for Example, make the red Part of the oblong colour'd Image, whatever Body they are reflected from, are always red; that is, all Bodies appear red in that Light: In the violet Light they are violet; green in the green; and ſo on in the other Colours.

This will appear by trying it with Vermillion, Orpiment, blue Bice, or Cloth of any Colour, *&c.*

Experiment 3. *Plate* XVI. *Fig.* 3.] Let the Light enter the dark Room thro' two Holes of a quarter of an Inch Diameter each, in the round Plate moveable in the Window; let theſe Beams be about two Inches aſunder, and reflected by the plane Mirror S.

The Plate and Mirror muſt be ſo diſpos'd, that the two Beams may fall upon two Priſms A A, which are laid horizontally upon the ſame Frame; ſo that the oblong Images, produc'd by the Refraction of thoſe Priſms, may touch one another at their Sides. Let one Priſm be turn'd a little about its Axis, that the red of one Image may be juſt on the ſide of the Violet of the other: Let theſe Colours, and none of the reſt, be intercepted by a wooden Ruler that has a white Paper paſted upon it, ſo that the

Red be at R, and the Violet at V, the reſt of each Image falling upon the Wall, which muſt be cover'd with a black Cloth. If any Perſon ſtand at O, and thro' the Priſm BB looks at thoſe Colours, R and V, (in the manner deſcrib'd concerning the Hole, in *Experiment* 4. of the foregoing Chapter) he will ſee the Colours ſeparated from one another, the Red at *r*, and the Violet at *v*; which therefore being reflected in going thro' the Priſm BB, undergoes a greater Refraction.

In the firſt Experiment of this Chapter we gave a Method, whereby to ſeparate the heterogeneous Rays better than in other Experi-
356 ments; in the following Experiments, Lights of divers Colours become much more homogeneous, which is requir'd in the ſixth Experiment of this Chapter.

Experiment 4. *Plate* XVII. *Fig.* 1.] Let the Sun's Light enter the dark Room thro' an Hole of $\frac{1}{8}$ of an Inch; the Sun-Beam muſt be reflected by the Priſm AA to the convex Lens V, which ſtands upon a Foot, and is about 3 or 4 Inches wide; the Length of the incident and reflected Rays taken together is about ſeven Feet; the Convexity of the Lens is ſuch, that the Foci of the Rays coming from the ſeveral Parts of the Hole, at the Diſtance of 10 or 12 Feet from the Lens, will form the Repreſenta-
* 711 tion of the Hole, if a Paper be held there *. Juſt beyond the Lens place the Priſm BB, whereby the Rays (as in the firſt Experiment of the foregoing Chapter) are diſpers'd; now placing the flat Board T, at the Diſtance at which the Rays coming from the ſeveral Points are collected, there will fall upon it a well terminated oblong colour'd Image RV, whoſe

Length

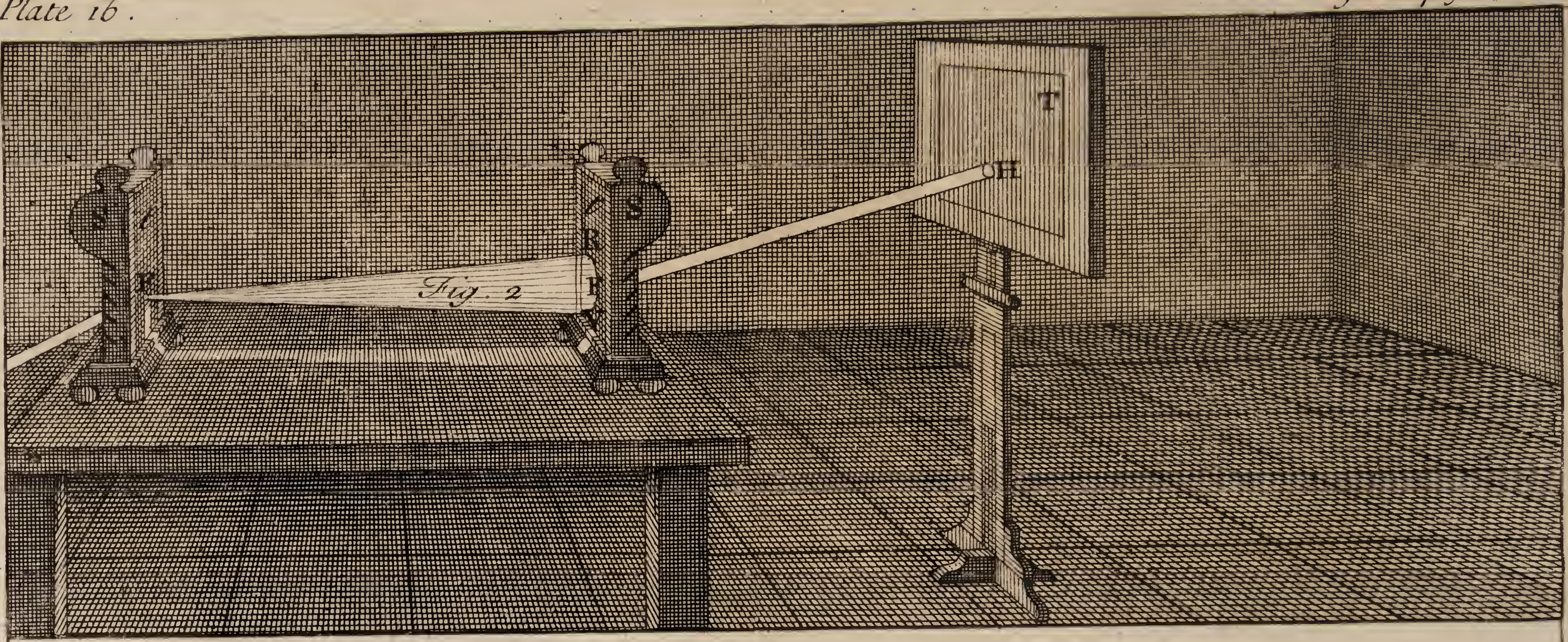


Fig. 2

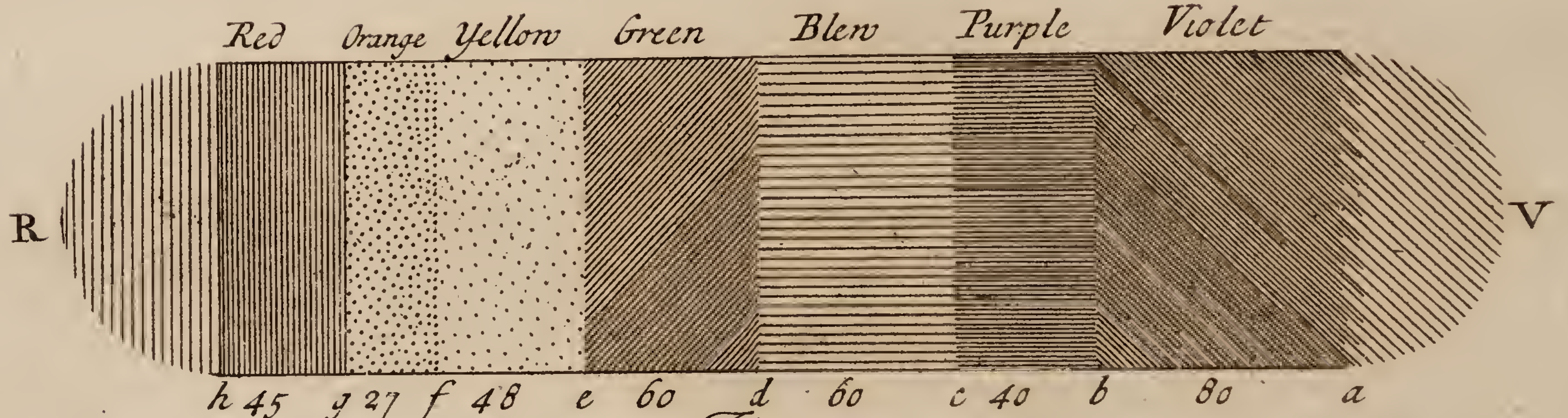

Red
Orange
Yellow
Green
Blew
Purple
Violet
R
V
h 45
g 27
f 48
e 60
d 60
c 40
b 80
a

Fig. 1.

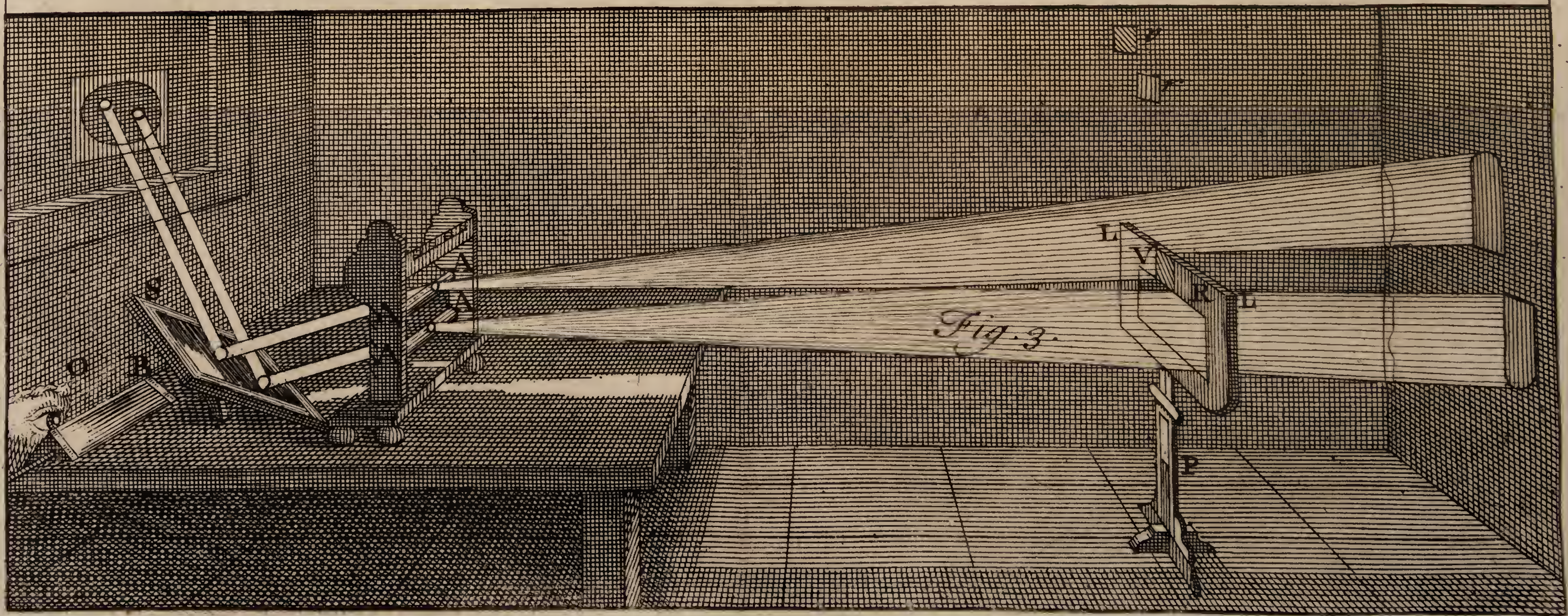

L
V
R
L
S
O
R
P
y
r

Fig. 3.

Length will have a greater Proportion to its Breadth than in other Experiments; and which therefore is made up of Rays more homogeneous*; and ſo much the leſs mix'd, as the Hole in the Window is the leſs. By moving forward or backward the Board **T**, one may find the Diſtance at which the Image is moſt diſtinct and terminated without a Penumbra. * 862

Now that the Rays ſeparated in this Experiment are homogeneous enough, is prov'd from this, that they can be no more diſpers'd by a new Refraction: And that this is the Property of homogeneous Rays, follows from their equal Refrangibility; which has already been confirm'd by an Experiment*, and is more fully demonſtrated by the following one. * 864

Experiment 5.] Take two Circles of Paper of an Inch Diameter each, and let Light fall upon them in ſuch a manner, that the one may have the homogeneous Rays of any Colour fall upon it, and the other may be enlighten'd by the Rays of the Sun; if both theſe Papers be look'd at thro' the Priſm at the Diſtance of ſome Feet, as in the third Experiment of this Chapter, the Circle enlighten'd by the heterogeneous Light, appears oblong, and ting'd with different Colours, as in the fourth Experiment of the foregoing Chapter; but neither the Colour nor Figure of the other Circle is chang'd.

Experiment 6.] Upon a white Paper draw black Lines parallel to one another, and about the ſixteenth part of an Inch wide; let theſe be enlighten'd by throwing upon the Paper the oblong Image, which is deſcrib'd in the fourth Experiment, ſo that the Lines may lie long-wiſe in the Image. Beſides this you muſt have a convex Lens, about five or ſix Inches wide, ſuſtain'd upon a Foot, ſuch as is repreſented at V (*Plate* XIX. *Fig.* 2.) which collects the red Rays that come from a radiant Point, ſix Foot diſtant from the Glaſs, at an equal Diſtance on the other Side. If this Lens be plac'd at the Diſtance of ſix Feet from the Image above-mention'd, the Parts of the black Lines that are enlighten'd by the Red falling upon the Paper, by means of the Rays which are collected by the Lens, will be exactly repreſented in the red Image at the Diſtance of ſix Feet; but you muſt bring the Paper forward about three Inches and a half, to make thoſe Parts of the Lines which are enlighten'd by the Purple, to appear diſtinct in that part of the Image which is of the ſame Colour: The intermediate Colours give Images at intermediate Diſtances; the Violet is ſo weak, that the Threads cannot be repreſented in it.

This Experiment does alſo confirm, that the Colour of reflected Rays is not chang'd by a new Refraction thro' the Lens; as alſo that the moſt refrangible Rays are more inflected than the others in paſſing thro' the Lens.

867 This laſt Experiment does alſo prove, *that the different Refrangibility of the Rays is the Cauſe that hinders the Perfection of Teleſcopes.* For the Foci of the Points that are equally diſtant, fall at different Diſtances from the Lens, according to their different Colours; whence all the Repreſentations of the Points are unequally diſtant from the Eye-Glaſs; and therefore they cannot be all perfectly ſeen thro' it.

868 Concerning the Reflexion of the Rays it is to be obſerv'd, that *thoſe Rays are more eaſily reflected totally, which have the greateſt Refrangibility*; for the greater is the Refraction of the Rays,

the leſs Obliquity is requir'd to make them be totally reflected *. * 793

Experiment 7.] Take a Priſm, plac'd as before *, in the Experiment where it was obſerv'd, * 790 that by moving the Priſm about its Axis, the Rays that firſt went thro', when their Inclination is encreas'd, becomes wholly reflected; but if the Priſm be gently mov'd in this Caſe, we ſhall perceive that the Violet Rays are the firſt which will be wholly reflected, then the Purple Rays, and and all the reſt in the ſame order, as they are in the oblong Image of the Sun, ſo often mention'd; which appears, if the reflected Rays be ſeparated by the Refraction of the Priſm.

CHAP. XX.

Of the Mixture of Colours, where we ſhall ſpeak of Whiteneſs.

THAT the Refrangibility and Colour of the Rays are not chang'd by the mixture 869 of Rays of different Refrangibility, has already been ſaid *, and now we muſt prove it by Experiments. * 863

Experiment 1. *Plate* XVI. *Fig.* 3.] This Experiment muſt be made in the ſame manner as the third of the foregoing Chapter; here you muſt make the Red R, and the Violet V be confounded and mix'd together, by throwing them upon the ſame part of the Ruler L L, which thereby will appear of a purple Colour in that place. But if a Perſon looks at them thro' a Priſm, the Colours will appear ſeparated; and therefore neither the Colour nor Refrangibility are chang'd by this Confuſion of Colours.

Experiment 2. *Plate* XVII. *Fig.* 2.] If the oblong colour'd Image of the Sun (of which mention was made in the firſt Experiment of the 18*th* Chap.) falls at R V upon the convex Lens L, mention'd in *Experiment* 4, of the foregoing *Chap.* which muſt be plac'd at ſix or ſeven Foot from the Priſm B B, the divergent Rays will converge by the Refraction of the Lens, and interſect one another at the Diſtance of 9 or 10 Feet at A; if the Board T be placed at a greater Diſtance, the Rays which diverge again after the Interſection, will fall upon it diſpers'd; and you will again have an oblong colour'd Image; but the Colours, by reaſon of the Interſection at A, will appear in a contrary Order, and will not be chang'd by having been mix'd together at A.

Experiment 3. *Plate* XVII. *Fig.* 2.] Every Thing ſtill remaining as in the former Experiment, if with a black Paper you intercept ſome of the Rays of the Image R V, which changes the Mixture (which this way may be varied in any manner) the Colours of the other Rays, that are again ſeparated, are no way chang'd.

870 *If the Rays of the Sun*, as they come to us, *are wholly reflected by any Body, that Body appears white*; for theſe Rays are an Heap, or Parcel
* 847 of Rays of various Colours *; whence we de-
858 duce, that *a Mixture of different Colours make a*
871 *Whiteneſs*; for if the Colours which are obſerv'd in the oblong Image of the Sun, ſo often mention'd, be mix'd and confounded together, in the ſame Proportion as they are in that Image, a Whiteneſs will be produced; which alſo proves, that in that reſpect the Rays are unchangeable. The Rays that come from the Sun appear white;

white; but if they are ſeparated, their Colours are diſcover'd; and if they be mix'd again, the Whiteneſs will be reſtor'd.

Experiment 4. *Plate* XVII. *Fig.* 2.] Things being diſpos'd as in the two foregoing Experiments; let the Board T be plac'd at A, in the very Place where all the Rays of the Image RV are confounded together; there will be a Whiteneſs at A; if with a black Paper you intercept the Red of the Image RV, the White will vaniſh, and the Colour at A be bluiſh; but if you intercept the violet and blue Rays, the White becomes reddiſh.

Experiment 5. *Plate* XVII. *Fig.* 3.] Take three triangular Priſms, made of Wood and Plates of Glaſs which contain Water, as BB, DD, DD; the Plates of Glaſs in each of them make an Angle of about 70 Degrees: The Length of the Plates is of ſix or ſeven Inches, and their Breadth of three Inches; theſe Plates are fix'd in another manner in the Priſms DD than in the Priſm BB, ſo as to make their Baſes bigger; that is, theſe Priſms are ſhorter and deeper than the other. Let the Sun's Rays be refracted thro' the Priſm BB, as in the 3d *Experiment* of the 18*th Chap.* and let the oblong Image of the Sun at the Diſtance of three or four Foot fall upon the Surface of the Priſm DD, plac'd parallel to the Surface of the Priſm BB, out of which the Rays go. In the ſecond Priſm the Rays undergo a contrary Refraction than in the firſt; becauſe of the Paralleliſm above-mention'd: And becauſe the Edge of the Angle form'd by the Glaſs Plates in the Priſm DD is turn'd upwards, and that of DD downwards; therefore the firſt Refraction is deſtroy'd by the ſecond, and the Rays go out of the Priſm DD parallel to one

another, and fall upon RV; for if the Priſms be brought together, ſo that the parallel Surfaces may touch one another, the Light will paſs thro' a Medium terminated with parallel Planes, (which is form'd by the two Priſms join'd together) thro' which Light, of any Degree of Refrangibility, will paſs without change of Di-
*628 rection *. Now the Priſms are ſeparated, that the heterogeneous Rays may be ſeparated, before they again become parallel; if theſe colour'd Rays fall upon the third Priſm DD, and in paſſing thro' it undergo a Refraction like that which they have undergone in paſſing thro' the firſt or ſecond Priſm; the Rays that go out at *r v* converge, on account of unequal Refractions in Rays of different Colours, and concur at A, in which place alſo Whiteneſs will be produc'd, as in the foregoing Experiment.

Experiment 6.] If an oblong colour'd Image of the Sun be made, after the manner deſcrib'd in *Experiment* 1. of the 18*th Chap*;. and a Perſon ſtanding at the Diſtance of the Priſm, that refracts the Light, looks at the Image thro' the ſaid Priſm, as was done in reſpect of the Hole in the fourth Experiment of the ſame Chap. he will ſee a round and white Image; the ſecond Refraction deſtroying the firſt; for thereby the Rays being again mix'd, enter the Eye, and in this Caſe make the Object appear white.

872 *The Mixture of all the Colours which are obſerv'd in the oblong Image of the Sun, are not neceſſary for producing White:* The Whiteneſs of the Sun's Rays is a little inclin'd to yellow; and therefore if part of the yellow Rays be taken out of the Mixture, the White will be the more perfect. From the Mixture of four or five Colours, in a juſt Proportion, White will be produc'd.

Primary, that is, homogeneous, *Colours being mix'd, produce innumerable Colours, different from the primary or homogeneous ones.* From a Mixture of other Colours one may produce a Colour like that which is homogeneous; but *when there can be no Difference obſerv'd by the naked Eye between an homogeneous and a mix'd Colour, one may perceive a ſenſible Difference thro' a Priſm.* 873

Experiment 7.] Thro' a Priſm look at any ſmall Objects, ſuch as Letters upon Paper, Flies, and other ſuch things; if they be expos'd to the common open Light, they will appear confus'd; but if they be enlighten'd by the homogeneous Light of the fourth Experiment of this Chapter, they will appear diſtinct when ſeen thro' the Priſm. 874

CHAP. XXI.

Of the Rainbow.

HAVING made an End of conſidering what relates to the Rays, whereby Bodies are enlighten'd; before we leave this Subject, we muſt explain a Phænomenon, which is too remarkable and common to be paſt by in Silence.

The *Iris* or *Rainbow* is what every Body has often ſeen; we muſt explain what is the Cauſe of it, having firſt laid down ſome Things for that Purpoſe.

Plate XVIII. *Fig.* 1.] *Let there be a denſe Medium encompaſs'd with a rarer, terminated by the Circle* B D F H. *Let homogeneous Rays that are parallel to one another fall upon it*, and let AB be one of theſe Rays; let the Semidiameter CB be drawn and continued to N; it will be perpendicular 875 cular to the Surface ſeparating the Mediums: A B N therefore is the Angle of Incidence: This Angle is equal to the oppoſite vertical Angle C B L, whoſe Sine is C L, perpendicular to B L and going thro' the Center; the Ray refractedtowards the Perpendicular *, and C B M is the Angle of Refraction, whoſe Sine is C M drawn from C perpendicular to B D: There is the ſame Proportion between ſuch Lines as CL and CM *, for every Ray as there is for A B. The Ray B D does in Part penetrate into the rarer Medium in the Direction D E, and in Part is reflected along D F; and makes the Angle of Reflexion C D F equal to the Angle of Incidence B D C *; whence B D and D F are equal. The Ray D F does alſo in part go out of the denſer Medium along F G, and is in Part reflected along F H; which in the ſame manner does in Part go thro' H I, and is in Part reflected: But this Reflexion, and other farther Reflexions and Refractions we ſhall not conſider; they are too weak, on account of the ſeveral Diviſions that the Light has undergone.

* 624

* 639

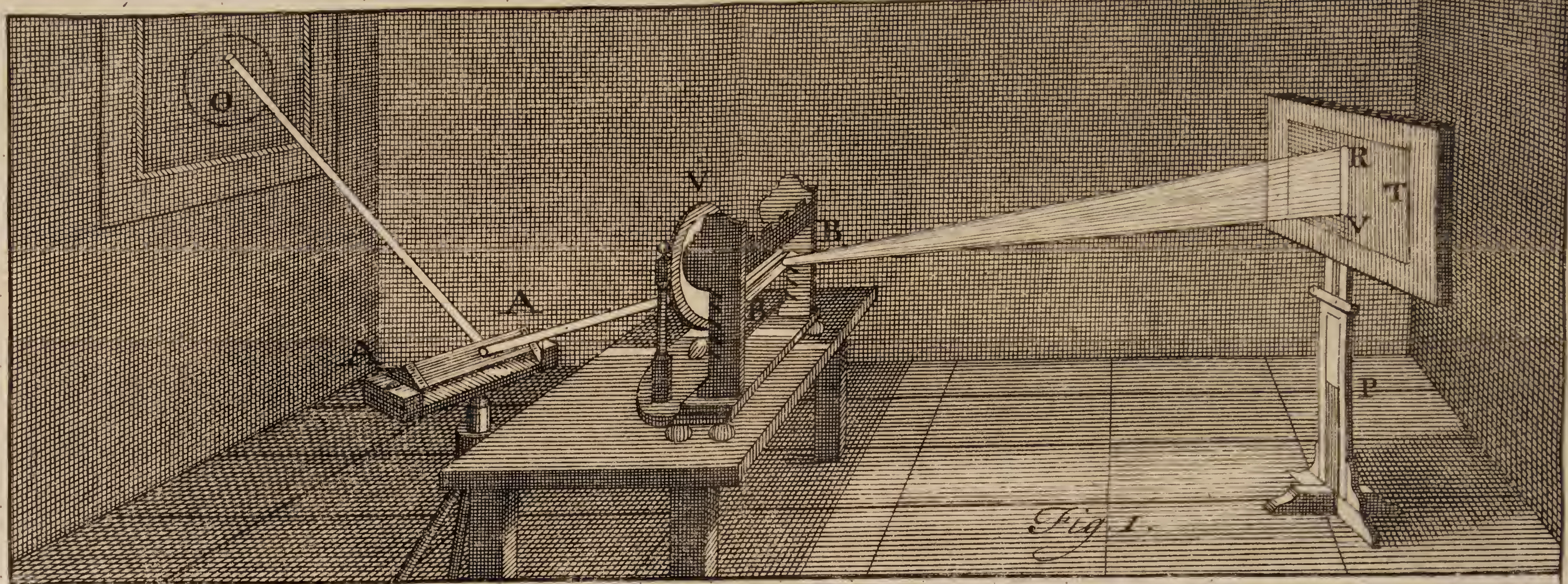
* 805

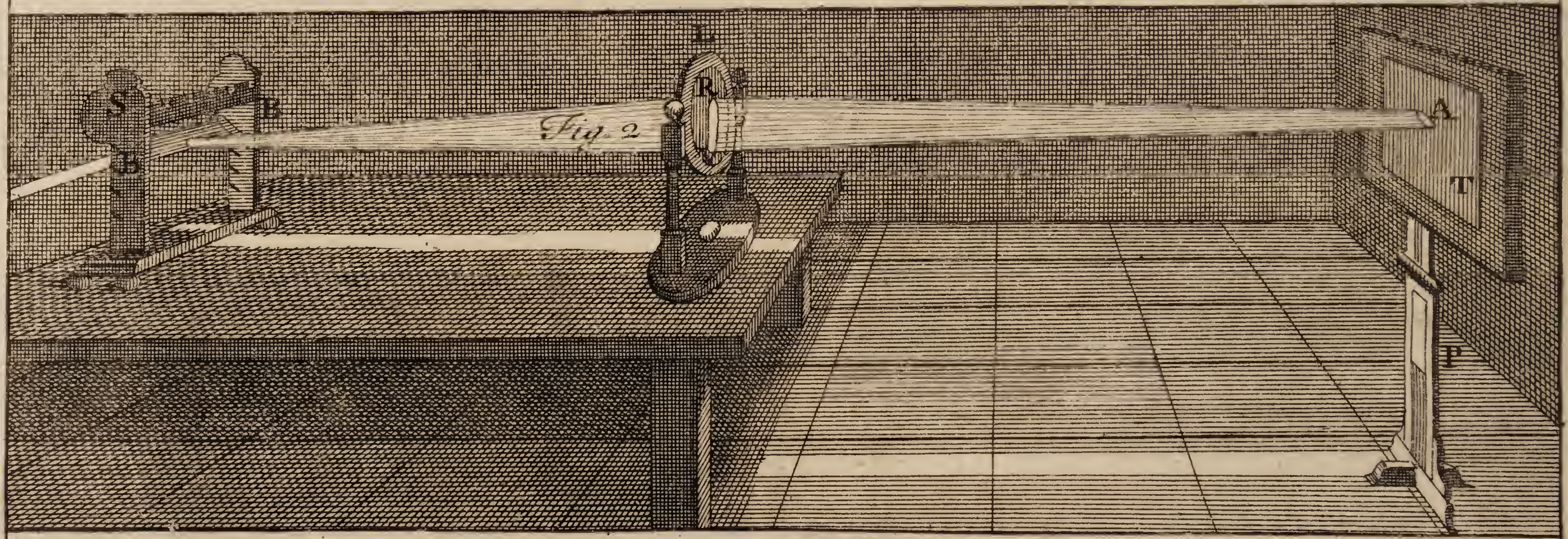
Plate XVIII. *Fig.* 1.] The Ray F G, which after one Reflexion goes out of a denſer Medium, makes the Angle G P A with the incident Ray AB, which varies in different incident Rays; therefore, tho' theſe Rays ſhou'd be parallel, *they will be ſcatter'd when they go out, after one Reflexion*, as may be ſeen by the ſecond Figure.

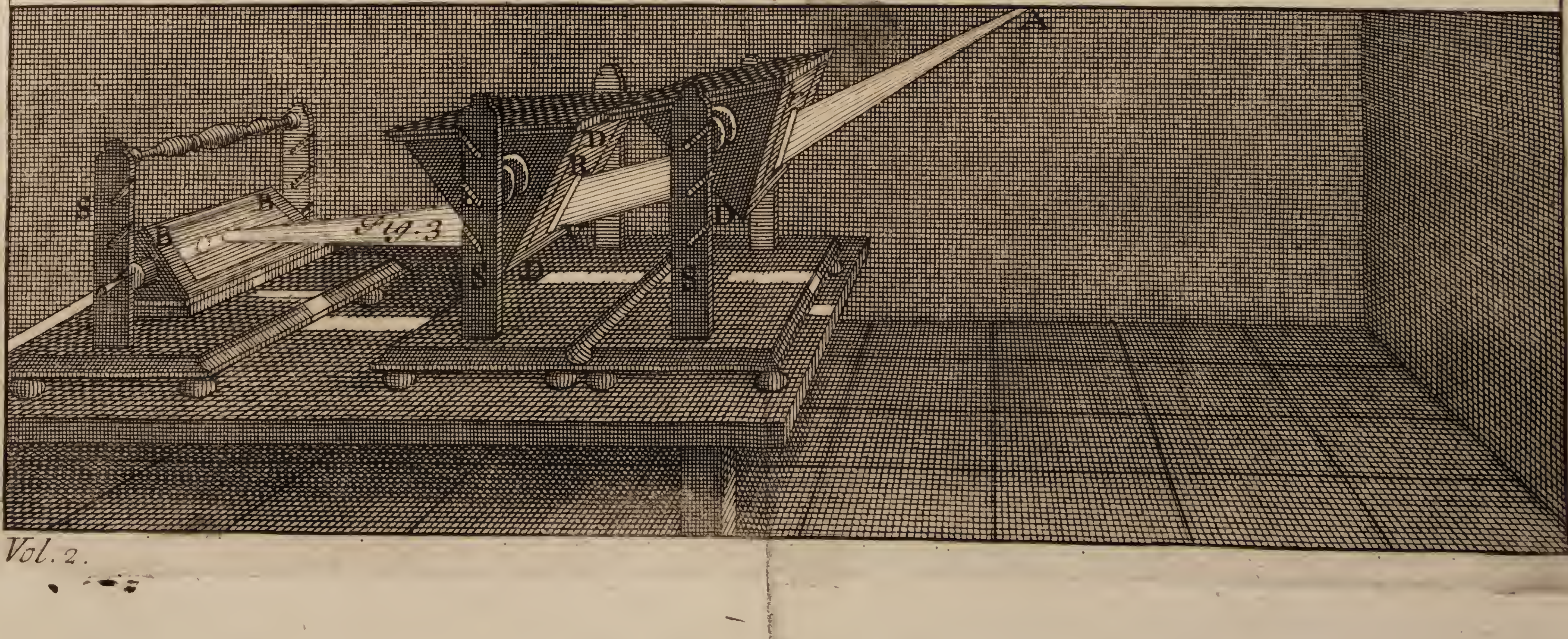
The Ray E E, which being continued, goes thro' the Center C, is not turn'd out of its way either by Reflexion or Refraction *.

* 806, 629

As you recede from this Ray, the returning Ray is continually leſs and leſs inclin'd to the incident one. So the Ray D D, which goes out of a denſer Medium along *d d*, and returns along that Line, makes a greater Angle with *d d*, than


O
V
B
A
R
T
V
P
Fig. 1.


L
R
S
B
Fig. 2
A
T
P


A
S
B
D
R
Fig. 3
S
O
D
S

than the intermediate Rays between D D and E E do make with their returning Rays, which go out of the denſer Medium.

876 Let B B be a Ray, in reſpect of which this Inclination is the leaſt of all, that is, which makes the Angle G P A (*Fig.* 1.) the biggeſt of all. Beyond B B the returning Rays are more inclin'd to incident ones; thus A A returns along *a a*.

877 From this Diſperſion *of the returning Rays* receding from the denſer Medium, they become continually weaker and weaker, and their *Colour cannot be perceived throughout the whole Space which they fill*, tho' the Colour of the incident Rays be vivid. *The Colour* in the returning Rays *is only ſenſible, where the neighbouring Rays are parallel*, and thoſe next to them diverge but very little; ſo that at a great Diſtance they are denſe enough to be perceiv'd. *Theſe only are ſaid to be efficacious*, and will be ſuch, when the incident Rays which are near one another being refracted, concur in the very Point of Reflexion.

Plate XVIII. *Fig.* 3.] Let A B, *a b* be neighbouring Rays parallel to one another, falling upon a circular Surface that terminates a denſer Medium; if theſe being refracted along B D, *b d*, do concur in D the Point of Reflexion, the reflected ones DF, D *f* will make the ſame Angles with one another as the incident ones D B, D *b*; therefore the refracted Rays F G, *f g* will be parallel * and efficacious *. In this Caſe the following Method will ſerve to determine the Angle made by the incident Ray with the returning one; that is, the Angle A P G, which here is the greateſt of all. * 627 * 877

878 Let us call the *Ratio* of I to R, that which is found between the Sines of the Angle of Incidence and Refraction, when the Light goes

out of a rarer Medium, by which a denſer is encompaſs'd, into a denſer contain'd in the Circle itſelf. Therefore, having drawn Cm perpendicular to bD, and the Arc mn with the Center C and Semidiameter Cm,
$I, R :: CL, CM :: Cl, Cm :: CL - Cl = Ll, CM - Cm = Mn.$

Draw Bo perpendicular to BL, and alſo Bp perpendicular to BD; and draw bp, ſo that it may make a right Angle with Bp; laſtly, join together by Lines the Points B, C, and M, m, the Triangles Bbo, BCL are ſimilar; for they are rectangular, and the Angles oBb and CBL (the Difference of each of which from a right Angle is the Angle oBC,) are equal.

It may be prov'd in the ſame manner, that the Triangles BMC and Bbp are ſimilar; the Triangle Mmn, which is rectangular at n, is alſo ſimilar to this, for the Sides Mn Bp, which are perpendicular to the Line BD, are parallel; as alſo Mm and Bb, becauſe the Lines BD, bD, are biſected at M and m into equal Parts. Therefore alſo Bb is the double of Mm, and Bp the double of mn.

Hence we deduce

$$BC, BL :: Bb, Bo.$$
$$BC, BM :: Bb, Bp.$$

Therefore

$BL, BM :: Bo = Ll, Bp = 2Mn :: I, 2R :: CL, 2CM$, by comparing theſe Proportions with the aforeſaid Proportion.

Now ſince the Squares of proportional Quantities, are themſelves proportional, you will have

$$BL^q, CL^q :: BM^q, 4CM^q.$$

Whence we deduce

$BL^q + CL^q = BC^q, BL^q :: BM^q + 4CM^q = BC^q + 3CM^q, BM^q = BC^q - CM^q = BL^q \times LC^q - CM^q.$

By ſubtracting the firſt and ſecond Term from the third and fourth, (which does not change the Proportion) you will have

$BC^q,\ BL^q :: 3\,CM^q,\ LC^q - CM^q :: 3\,R^q,\ I^q - R^q$; for there is the ſame Ratio between C M and L C as between R and I.

If therefore you know the Ratio between R and I, you have the Ratio between the Semidiameter B C, and the Line B L, which is the Sine of the Angle B C L, which Angle therefore is given; and by Conſequence you have the Arc B N, and alſo F G, for they are equal.

Having the Sine B L, you have alſo the Sine of the Angle B C M; becauſe (as we have ſhewn before)

$$BL,\ BM :: I,\ 2\,R.$$

Therefore the Arc B D is determin'd, to which D F is equal.

879 Hence we may eaſily find the Arcs N H and B F; if the former be taken out of the latter, and the Remainder be divided into two equal Parts, we ſhall have, as is well known, the Meaſure of the Angle A P G.

When the Ratio between I and R varies, the Angle A P G is changed, which therefore becomes different, according to the different Refrangibility of the Rays.

880 *If the aboveſaid Surface be enlightened by heterogeneous Rays,* as they flow from the Sun, *the efficacious Rays of different Colours do not make equal Angles with the incident ones, and* ſo *by the help of this Refraction the Colours are ſeparated.*

Plate XVIII. *Fig.* 4. *Experiment* 1.] Let the Sun's Light enter the dark Chamber, thro' a Slit in the moveable round Plate O, and being horizontally reflected from the Looking-glaſs S, let it paſs thro' a Slit *i* in the little Board or Stand T;

630 as has been before explain'd. Take a Phiol exactly cylindric, made of clear Glaſs, and full of Water. Let the Beam or Ray at *f g* fall upon the Surface of the Phiol, it will be refracted in the Water towards *h i*, and there reflected, and will go out of the Phiol at *l m*. The Phiol may be eaſily ſo placed, as to make theſe Rays efficacious; and, becauſe of the Breadth of the incident Ray or Beam, efficacious Rays of all Colours will go out of the Phiol in the ſame Time; for they are very little diſtant from one another in their Incidence. If theſe efficacious Rays fall upon a white Paper, at the diſtance of 4 or 5 Feet from the Phiol, they will produce vertical *Faſciæ* or Pillars, of various homogeneous Colours, ariſing from the efficacious Rays of each Colour; if alſo, the Eye be placed any where at the Diſtance of ſome Feet from the Phiol, as at N, in theſe efficacious Rays, it will ſee in the Phiol that Colour whoſe Rays enter the Eye, and by a ſucceſſive Motion of the Eye it will *861 perceive all the aforemention'd Colours.*

881 *Plate* XVIII. *Fig.* 5.] But as to thoſe Rays, which after a double Refraction in a denſer Medium emerge, they will be efficacious, if they are parallel after the firſt Reflection; for then F H, *f h* are in the ſame manner inclin'd to H *h* as B D, *b d* to B *b*; and therefore ſuppoſing the incident Rays A B, *a b* to be parallel, the *627 emerging Rays H I, *h i*, will alſo be parallel.*

In this Caſe *d* D is half of the Difference between the Arcs D F and *d f*, or D B and *d b*, but their Difference is B *b* — D *d*; if therefore this laſt be ſubtracted from the other, there will remain the Double of the Arc D *d*, whoſe Triple therefore is B *b*. If by Lines the Points D, *d*, and B, *b*, be join'd, the Triangles B E *b* and D E *d* will be ſimilar, as is known; which therefore

fore obtains, tho' the Arcs B *b*, D *d* be ſo very ſmall, that they may be taken for right Lines.

There is therefore that Ratio between E D and E *b*, which obtains between theſe Arcs, that is, E D is the third part of E *b*, or E B; becauſe we ſuppoſe the Arc B *b* to be extreamly ſmall. M D therefore is divided into two equal Parts at E; and M E is a third Part of E B.

Now if (as in *Fig.* 3.) the Triangles B *o b*, B *p b*, and M *m n*, be form'd, M *m* will be the third Part of B *b*, and B *p* the Triple of M *n*; now if, *mutatis mutandis*, we apply to this Figure what was demonſtrated with reſpect to *Fig.* 3.* * 878 becauſe in this B *p* is equal to 3 M *n*, whoſe Square is $9\,Mn^q$, we ſhall have

$$BC^q,\ BL^q :: 8R^q,\ I^q - R^q.$$

From which Proportion, as was ſaid of *Fig.* 3. the Arc B N may be diſcover'd, to which H G is equal; and becauſe in this Caſe

$$BL,\ BM :: I,\ 3R,$$

You have alſo the Arc B D, to which (becauſe the Angles of Reflection are equal to the Angles of Incidence) * D F and F H are equal. * 805

882 From which Things being found, we may eaſily deduce the Arcs G F D N, and B H, whoſe half Difference is the Meaſure of the Angle H P B, which is form'd by the emerging Ray with the incident one; which Angle in this Caſe is the leaſt of all that are like it, and is different according to the different Refrangibility of the Rays. 883 Whence alſo in this Caſe the *efficacious Rays of various Colours, ſuppoſing the incident ones parallel, are ſeparated after a double Reflection.*

Plate XVIII. *Fig* 4. *Experiment* 2.] This Experiment is perform'd after the ſame manner as the former, only the Situation of the Phiol muſt be a little chang'd, that, after two Reflections in the Phiol, the Rays may come to the Eye or Paper towards N.

What has been hitherto explain'd, may be applied *to the Rainbow*; for which Phænomenon *it is requir'd, that Drops of Water ſhould be ſuſpended in the Air; that the Spectator ſhould be placed with his Back towards the Sun, between it and the Drops; and that there ſhould be a dark Cloud behind the Drops,* that the Colours may be more ſenſible, which are ſcarcely perceiv'd, if vivid Light enters the Eye at the ſame Time.

If theſe Things being ſuppos'd, we conceive
each Drop to be cut by Planes paſſing thro' the
Sun and the Eye of the Spectator; what has
been demonſtrated of a Medium, terminated
* 878, with a circular Surface,* may be applied to each
879, of theſe Sections.
880,

881, Now here we ſpeak of Rays that penetrate
882, out of Air into Water. In red Rays; that is,
883. thoſe which are leaſt of all refrangible, the *Ratio* between the Sine of the Angle of Incidence
and the Sine of the Angle of Refraction; that
is, between I and R, is that of 108 to 81; or
which is the ſame, of 4 to 3; with which Numbers, if the Computation be made, the Angle
* 879 A P G (*Fig.* 3.) will be 42 Deg. 2 Min.*, and
the Angle A P I (*Fig.* 4.) will be 50 Deg. 57
* 882 Min.* If we ſpeak of the violet Rays, I and
R are to one another as 109 to 81; which Numbers give the Angles A P G (*Fig.* 3.) of 40 Deg.
* 879 17 Min.*, and A P I (*Fig.* 4.) of 54 Deg. 7 Min.*
* 882

Plate XIX. *Fig.* 1.] Let the Drops be ſuppos'd to be diffus'd in the Air, and enlighten'd by the Sun's Rays, which are parallel to one another, and to the Line O F, that paſſes thro' the Eye of the Spectator. Let the Lines *e* O, E O, *b* O, B O, be conceiv'd to be drawn; and let the Quantity of the following Angles be thus, (*viz.*) *e* O F of 40 Deg. 17 Min. E O F 42 Deg. 2 Min. *b* O F 50 Deg. 57 Min. B O F 54 Deg. 7 Min. Theſe ſame Lines with the incident Rays *d e*, D E, *a b*, A B, form Angles that are reſpectively equal to the aforemention'd; therefore, if the Drops be conceiv'd at *e*, E, *b*, B, the violet efficacious Rays, after one Reflexion in the Drop *e*, enter the Eye; and the red efficacious Rays come to the Eye from the Drop E; in like manner after one Reflexion, the other intermediate Colours are obſerv'd between *e* and E, in the abovemention'd Order*. *861 After two Reflexions in the Drop, the efficacious red Rays come to the Eye from the Drop *b*; and the efficacious violet ones from the Drop B; the intermediate Colours appear between theſe Drops after the ſame Manner as between E, *e*; but they are diſpos'd in a contrary Order, and by reaſon of their double Reflexion are alſo weaker.

Let us conceive a Line at O *e*, to be revolv'd about a fix'd Line O F, preſerving the Angle *e* O F, and to form a Cone or part of a conic Surface: in every Situation the Line *e* O will, with the Rays of the Sun that are parallel to one another, and to the Line O F, form an Angle of 40 Deg. 17 Min. 885 *If* therefore *the Drops be diffus'd* near part of the Surface of this Cone at the ſame or different Diſtances, *the Eye will ſee a* violet Arc or Bow: The ſame may be ſaid of the other Colours; and therefore Drops being ſuſpended in the Air, it ſees an Arc or *Bow* of the Breadth *e* E, *ting'd with the homogeneous Colours* before-mention'd*, *861 that are diſpos'd in the ſame order as in the Experiments with Priſms; becauſe the heterogeneous Rays are ſeparated as much in the Drops as in the Priſm*. *852

886 By the ſame way of reaſoning it is plain, *there will be a broader* Arc or *Bow, ſurrounding the firſt, in which the ſame Colours will appear in a contrary Order, and Weaker.*

Experiment 3.] Hang up a black Cloth in the Light of the Sun; and let a Spectator look at it ſtanding between the Sun and the Cloth; then if Water be made to fall in ſmall Drops between the Spectator and the Cloth, the Spectator will ſee a Rainbow, at leaſt the inner one.

CHAP. XXII.

Of the Colours of thin Plates.

WE paſs on to the Colours of natural Bodies; and before we go any farther, we think it proper to examine thin Plates. Whoever attentively has obſerv'd very thin Glaſs, or Bubbles made of Water thicken'd with Soap, muſt have perceiv'd ſeveral Colours in them. Rays of Light, by help of a thin tranſparent Plate, are ſeparated from one another, and *ac-*
887 *cording to the different Thickneſs of the Plate, the Rays of ſome Colours are tranſmitted, and thoſe of others are reflected; and the ſame very thin Plate is of another Colour, when ſeen by the tranſmitted Rays, than when ſeen by the reflected ones.*

Experiment 1. *Plate* XVIII. *Fig.* 6.] Take two Object-Glaſſes belonging to long Teleſcopes, AB and CD; and let one of them be laid upon the other; then let them be preſs'd together hard, and in the middle, where the Glaſſes touch one another, you will ſee a tranſparent Spot, which is encompaſs'd with colour'd Circles. If the Light reflected by the Air that is between the Glaſſes comes to the Eye at O, there will appear a black Spot; and the Colours, which as you recede from the Center are ſo diſpoſed, that by reaſon of the ſame Colours coming over again, they may be referr'd to ſeveral Orders, they will be as follows; BLACK, Blue, White, Yellow, Red: VIOLET, Blue, Green, Yellow, Red: PURPLE, Blue, Green, Yellow, Red: GREEN, Red; which Colours are alſo encompaſs'd with other Colours; but as you recede from the Center; grow continually weaker and weaker.

If the Light paſſes thro' the Glaſſes to the Eye at O, the tranſparent Spot which tranſmits all the Rays is White; and by that Series, as you recede from the Center, there will appear Colours, which are alſo referr'd to ſeveral Orders contrary to thoſe above-mention'd: WHITE, yellowiſh Red, Black, Violet, Blue; WHITE, Yellow, Red, Violet, Blue: GREEN, Yellow, Red, bluiſh Green: RED, bluiſh Green, which are alſo encompaſs'd with weaker Colours.

Experiment 2.] Blow up ſoap'd Water into a Bubble, to form a thin Plate of Water. Let this be cover'd with a very clear Glaſs, leſt, by the Agitation of the Air, the Colours to be obſerv'd in that Bubble, ſhou'd be confounded by the Motion of the Water. Such a Bubble, becauſe the Water continually runs down every way, is very thin at Top, and the Thickneſs in going down is continually encreas'd; and for the ſame reaſon the Thickneſs of the whole is continually diminiſh'd. Before the Bubble breaks, the Top of it becomes ſo thin, as to tranſmit the whole Light and appear black. If in that Caſe the Bubble be obſerv'd by reflected Light, when it is enlighten'd by the Reflexion of a whitiſh Sky, and the extraneous Light is intercepted by placing any black Body behind the Bubble; the black Spot above-mention'd will appear, and be encompaſs'd with the ſame colour'd Circles, diſpos'd in the ſame Order as about the black Spot in the former Experiment. As the Water deſcends, the Rings are continually dilated till the Bubble burſts.

When the extreme Circumference of the Bubble appears Red by the reflected Rays, if it be look'd at ſo as to be ſeen by the tranſmitted Rays, it will appear Blue; and generally the Colours produc'd by tranſmitted and reflected Rays, in the ſame manner as in the foregoing Experiment, are oppoſite to one another.

888 By comparing theſe Experiments, it follows that *if we encreaſe the Thickneſs of a very thin Plate, its Colour will be chang'd,* and *there will be the ſame Changes ſucceſſively, and in the ſame Order, whether the Plate be form'd out of a rarer or a denſer Medium.* For in the Plate of Air, between the Glaſſes, and the watery one in the Bubble, whoſe Thickneſs encreaſes as it goes farther from the middle, the Colours will be in the ſame Order.

889 Yet *in a denſer Plate a leſs Thickneſs is requir'd than in a rarer, to have it ting'd with the ſame Colour.*

Experiment 3.] Every thing being diſpos'd as in Experiment 1. if you wet the Edges of the Glaſſes a little on one ſide, the Water will by degrees inſinuate itſelf between the Glaſſes; and there will be obſerv'd the ſame colour'd Circles as in the Air, neither will their Order be changed, but the Circles will be leſs; when the Water is got as far as the Center, all the Portions of the Circles in the Water will be ſeparated from the Portions of the Circles in the Air, and be all reduc'd into a leſs Space.

The Colour of a Plate depends upon its Thickneſs * *and Denſity, and not upon the encompaſſing Medium.* 890 * 887 * 889

Experiment 4.] If you take a piece of Iſing-glaſs or Talk, ſo thin as to have it colour'd, the Colours will not be chang'd by wetting it; that is, if inſtead of Air the Plate is encompaſs'd with Water.

The Colour of the ſame Plate is ſo much the more vivid, as its Denſity differs more from the Denſity of the circumambient Medium. This is prov'd by the foregoing Experiment, in which the Colours of the Plate, when wet, are more languid than thoſe of the ſame Plate encompaſs'd with Air. In the third Experiment alſo the Colours are leſs vivid than in the ſecond; in both there is a Plate of Water; but in the ſecond Experiment it is enclos'd with Air, and in the other with Glaſs; but Water and Glaſs differ leſs in Denſity than Air and Water. 891

If Mediums equally differ in Denſity, the Colours will be more vivid, if the denſer be encompaſs'd with the rarer: For a very thin Glaſs Plate, which is colour'd on account of its Thinneſs, being encompaſs'd with Air, the Colours will be more vivid than in *Experiment* 1. in which a Plate of Air is encompaſs'd with Glaſs. 892

A Plate of the ſame Denſity, encompaſs'd with the ſame Medium, will reflect ſo much the more Light, as it is thinner. 893 *Yet if the Thickneſs be too much diminiſh'd, it does not reflect the Light.* 894 All this is plain from the foregoing Experiments; in the three firſt, the colour'd Circles which are the leaſt, and which are alſo the thinneſt, reflect Light beſt of any; but in the Center, where the Spot is the thinneſt of all, there is no ſenſible Reflexion; as this clearly appears in the ſecond: In the firſt there is alſo a very thin Plate of Air, which does not reflect Light; for the tranſparent Spot in the Center is much bigger than thoſe Parts of the Surfaces of the Glaſſes which immediately touch by the yielding inwards of the compreſs'd Parts.

895 *If there are Plates of the ſame Medium, whoſe Thickneſs are in an Arithmetical Progreſſion of* the Natural Numbers 1, 2, 3, 4, 5, 6, 7, &c. *If the thinneſt of them all reflects any homogeneous Rays, the ſecond will tranſmit the ſame*, the third again will reflect them, *and the Rays will be alternately reflected and tranſmitted*; that is, the Plates, whoſe Thickneſs in the abovemention'd Progreſſion anſwer to the odd Numbers 1, 3, 5, 7, *&c.* reflect the Rays which the others tranſmit, whoſe Thickneſſes anſwer to the even Numbers 2, 4, 6, 8, *&c.*

This Property of the Plates obtains in reſpect of any ſort of homogeneous Rays, with this Difference, that different Thickneſſes are requir'd for different Colours, as has been ſaid before *; the thinneſt of all for reflecting Violet, and they muſt be thickeſt for reflecting Red; if the Thickneſſes are intermediate, the Rays of an intermediate Refrangibility are reflected, that is, *as the Refrangibility of the Ray increaſes, the Thickneſs of the Plate, that reflects it, is diminiſh'd.* 896

* 887

Experiment 5.] Let the Experiment be made in a dark Room to produce the oblong Image of the Sun upon a Paper, ſuch as is mention'd in *Experiment* 1. *Chap* 18. Take two Object-Glaſſes of long Teleſcopes (ſuch as were mention'd in the firſt Experiment of this Chapter) let them be preſs'd together, and ſo diſpos'd, that every ſingle Colour of the Image abovemention'd may be ſucceſſively ſeen in them as in a Looking-glaſs; that is, that the Glaſſes may be ſucceſſively enlighten'd by ſeveral homogeneous Rays; which may be done, by gently moving about its Axis the Priſm that ſeparates the Rays to make the oblong Image. The Rings, mention'd in the firſt Experiment, appear, but more in Number, and only of one Colour; by reaſon of the Unchangeableneſs in homogeneous Rays:* In the Interſtices of thoſe Rings the Rays are tranſmitted, as plainly appear by holding a Paper behind, upon which the tranſmitted Rays will come; the Rings are leaſt of any, when they are violet; then are ſucceſſively dilated, conſidering the following Colours, quite to the Red. The Rings being of any Colour, if you meaſure exactly the Diameters of the Circles that may be conceiv'd to be in the middle of the Breadth of the Rings, the Squares of their Diameters will be to one another as the odd Numbers 1, 3, 5, *&c.* and meaſuring in the ſame Manner the Diameters of the Circles in the middle of every one of the Interſtices between the Rings, the Squares of their Diameters will be as the even Numbers 2, 4, 6, *&c.* Now in uſing ſpherical Glaſſes, the Thickneſſes of the Plate of Air, in the Circles above-mention'd, are as the even and odd Numbers.

*863

DEFINITION.

An homogeneous Colour, in a Plate of any Medium, is ſaid to be of the firſt Order, *if the Plate be the thinneſt of all thoſe that reflect that Colour; in a Plate whoſe Thickneſs is triple, it is ſaid to be* of the ſecond Order, *&c.* 897

*A Colour of the firſt Order is the moſt vivid of any; and ſucceſſively in the following Orders, in the ſecond, third, &c. it is leſs and leſs vivid.** 898

*893

When a Plate of Air is enlighten'd with heterogeneous Rays, as that between the Glaſſes

of the Teleſcopes, or any *Plate* like it of any other Subſtance, as in *Experiment* 1. and 2. ſeveral of the Rings ſeen in the laſt Experiment are confounded together, and that Colour is ſeen
899 which is made of their Mixture; for *the ſame Thickneſs of a Plate is often requir'd, for reflecting different Colours of various Orders:* So a Plate which reflects the Violet of the third Order, does alſo reflect the Red of the ſecond Order, as may be deduc'd from the laſt Experiment, if you attentively conſider it: Therefore in the firſt and ſecond Experiment, the third Violet Ring is confounded with the outward Edge of the ſecond red Ring, and a purple Colour is produc'd; yet all the Red of the ſecond Order is not abſorb'd, becauſe the red Ring is wider than the violet one.

900 *The more the Thickneſs of a Plate is encreas'd, the more Colours it reflects, and different ones,* of different Orders. The violet Plate of the tenth Order falls in with the blue one of the ninth Order, and the yellow one of the eighth Order, and laſtly with the red one of the ſeventh Order; and the Colour of the Plate is made up of a mixture of thoſe Colours.

901 *If* in the firſt and ſecond Experiments, *a Spectator looks obliquely upon the Plates,* ſuch as that made of Air, and that which is made of Water, the Rings will be dilated as they are ſeen more obliquely, that is, in that Motion of the Eye *the Colour of the Plate* in a determinate Place *is chang'd*; yet the Dilatation is greater in the firſt
902 Experiment; which proves, that *the Colour is more chang'd by the Obliquity of the Rays, if the Plate be encompaſs'd with a denſer Medium, than if it be enclos'd by a rarer Medium.*

Plate XVIII. *Fig.* 7.] The Demonſtration of which Propoſition is eaſily deduc'd from the

Laws of Refraction. Let L and *l* be thin Plates;
the laſt encompaſs'd with a denſer, and the firſt
with a rarer Medium; let them both be of the
ſame Thickneſs: If the Rays A B, *a b*, equally
inclin'd to the Plates fall upon them, there will
be at L a Refraction towards the Perpendicu-
lar;* on the contrary, at *l* the Ray is refracted *624
from the Perpendicular;* and tho' B D and *b d* *625
are equal, *b c* is longer than B C; and therefore
there is a greater Change in the Motion of the
Light in the Plate *l* than in the Plate L. *The* 903
Denſity of the Plate L *being encreas'd, the Medium*
with which it is encompaſs'd remaining the ſame, there
will be a leſs Difference between B C and B D,
and therefore a leſs *change of Colour*; and *if the* 904
refracting Power of the Plate be ſo *encreas'd*, that
the refracted Rays (whatever be the Obliquity
of the incident ones) ſhall not ſenſibly differ,
there will be no ſenſible Difference in the Colour of the
Plate, whatever Situation the Eye is plac'd in.

Hence we may eaſily deduce, that *the Colour* 905
of ſome Plates will vary by changing the Poſition of
the Eye, and that the Colour of others is permanent.

CHAP. XVIII.

Concerning the Colours of Natural Bodies.

WHAT relates to the Colours of all ſorts of Bodies may be eaſily deduc'd, from what has been hitherto explain'd.

We have ſhewn that the Rays of Light have Colours peculiar to themſelves and unchangeable, ſo as not to be chang'd by Reflexion.* *863

Therefore *the Rays reflected from Bodies, ac-* 906
cording as a greater or leſs Refrangibility, is proper
to the Colour of the Body itſelf, have a greater or leſs
Refrangibility.

Experiment 1.] In the middle of a black Paper fix two ſquare Pieces of Ribbon, the one Red and the other Violet, which muſt be join'd ſo as to touch one another at their Sides, in the ſame Manner as the red and violet Colours in the third Experiment of *Chap.* 19. The black Paper muſt be ſo plac'd, that the Ribbons may be well enlighten'd by the Light that comes into the Room thro' the Window: If a Spectator looks at theſe Ribbons thro' a Priſm, as in the Experiment above mention'd, the Colours will appear ſeparated in the ſame Manner as in that Experiment.

Experiment 2. *Plate* XIX. *Fig.* 2.] Place the two Ribbons mention'd in the former Experiment at R and V; let the laſt be violet, the firſt red; let them be enlighten'd by the Flame of a Candle; at ſix Feet diſtance place the convex Lens V; (of which mention has been made in *Exper. 6. Cap.* 19.) at the Diſtance of about ſix Feet, you will have the Repreſentation of the Ribbon R upon a white Paper at *r*; at a leſs Diſtance you will have an exact Repreſentation of the other at *v*. You may determine when the Repreſentations are exact, by binding black Threads upon the Surface of the Ribbons; for theſe Threads appear diſtinctly, where the Repreſentation is exact.

907 That *Bodies have various Colours, becauſe different Rays are reflected from Bodies differently colour'd*; and that *a Body appears of that Colour, which ariſes from the Mixture of the reflected Rays*, may not only be deduc'd from the foregoing Experiments, but may be alſo demonſtrated directly by others.

Experi-

Plate 18.

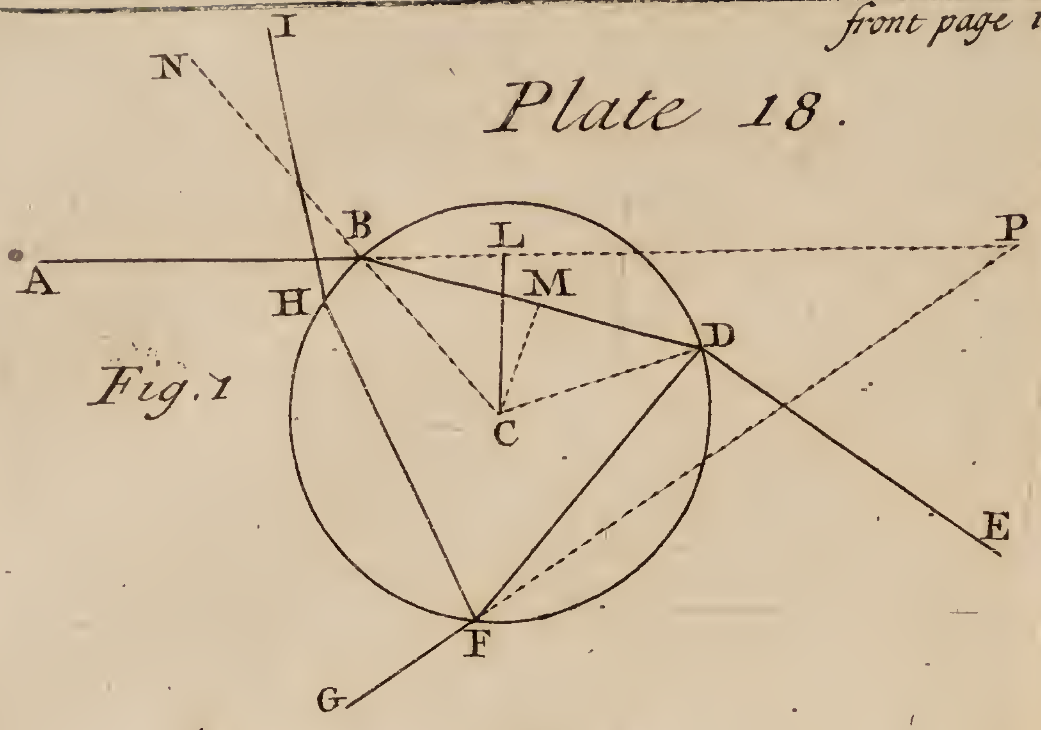

N
I
B
L
P
A
H
M
D
C
E
F
G

Fig. 1

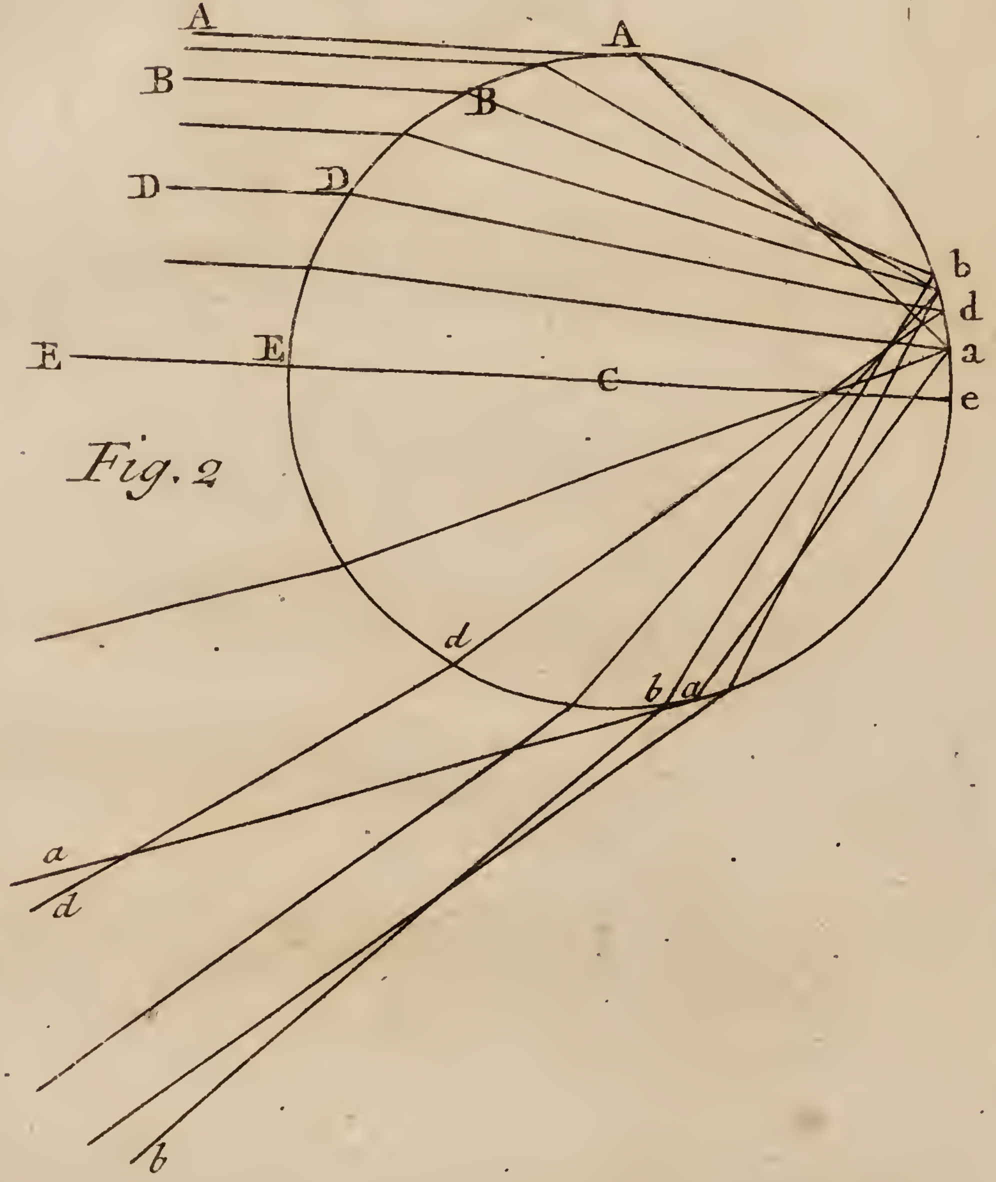

A
A
B
B
D
D
E
E
C
b
d
a
e
d
b
a
a
d
b

Fig. 2

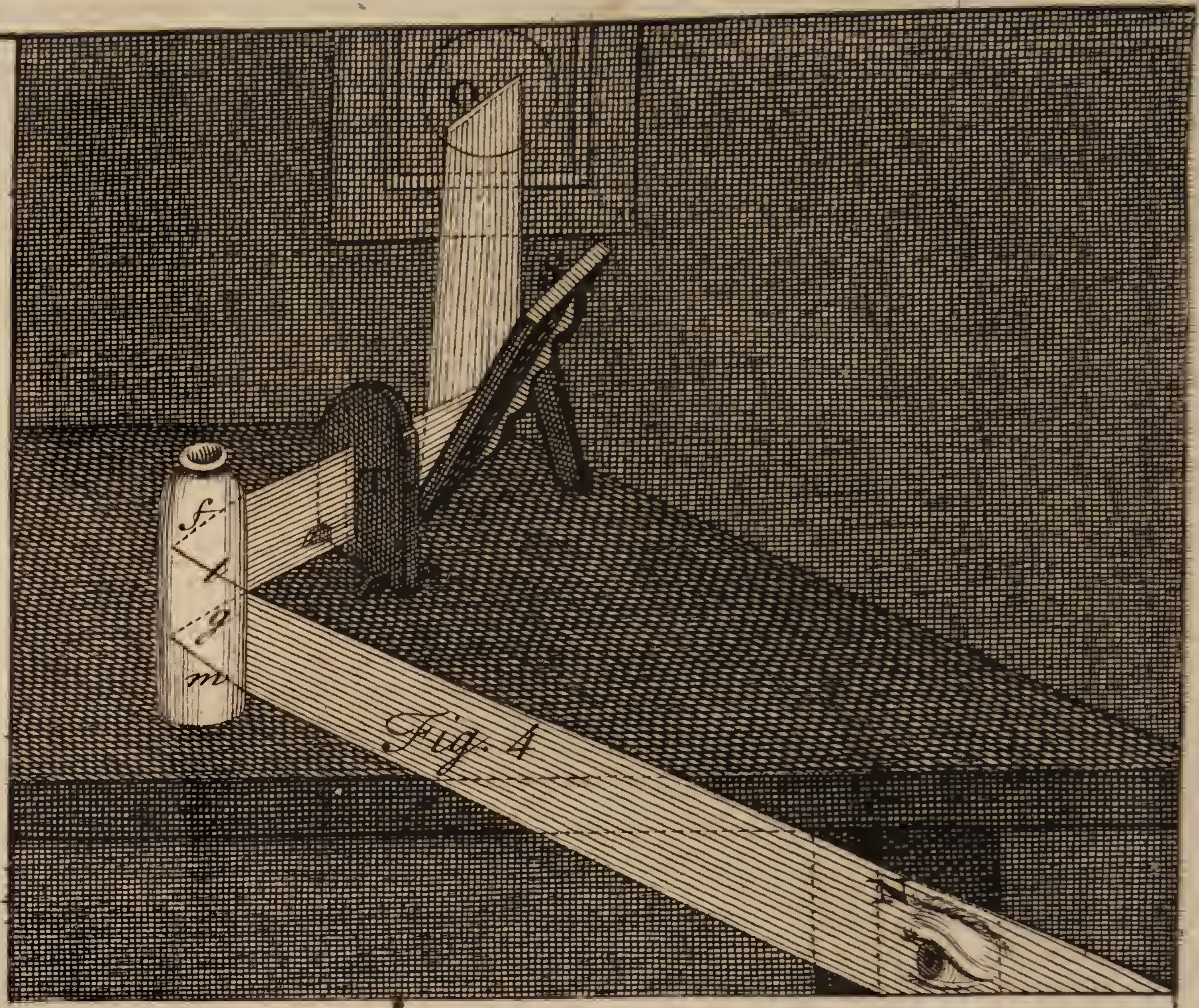


Fig. 4

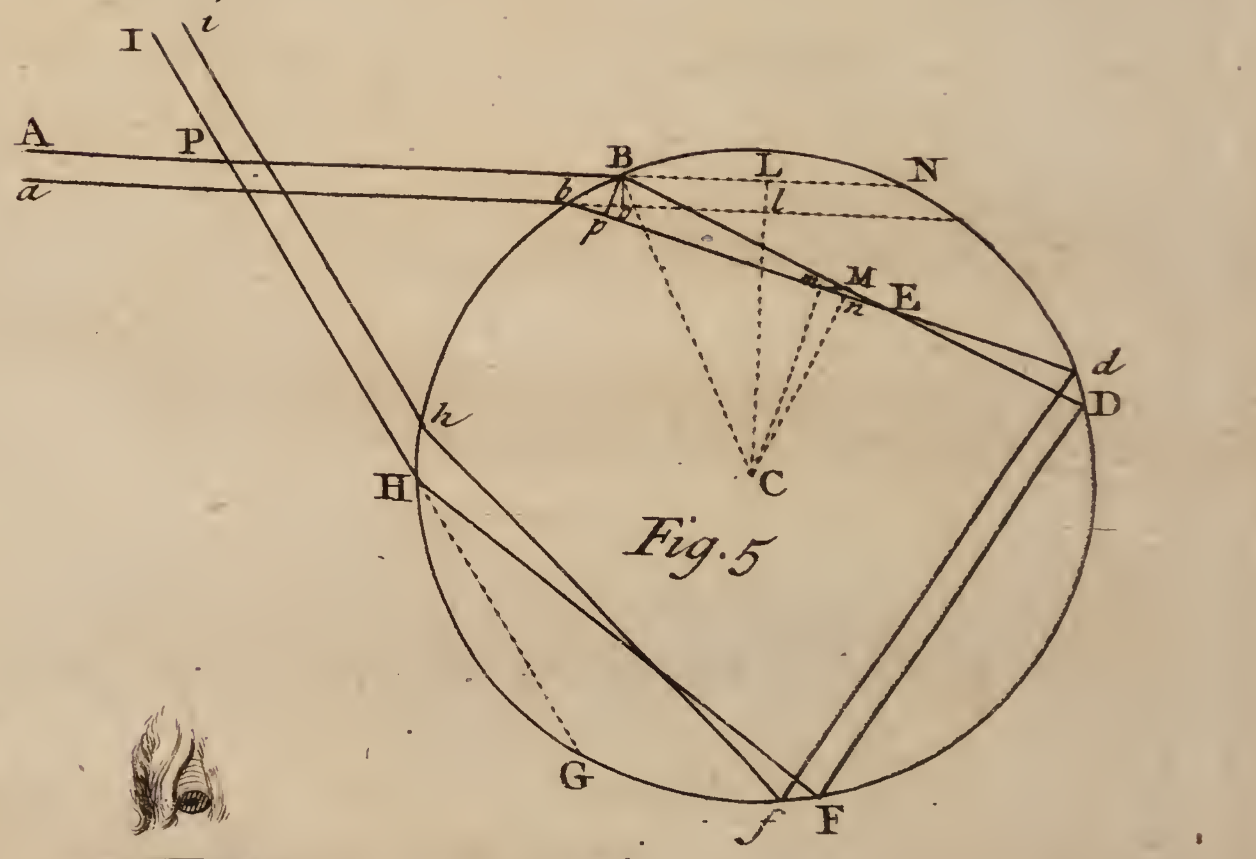

I
i
A
P
B
L
N
a
b
l
p
M
m
E
d
D
h
C
H
G
f
F

Fig. 5

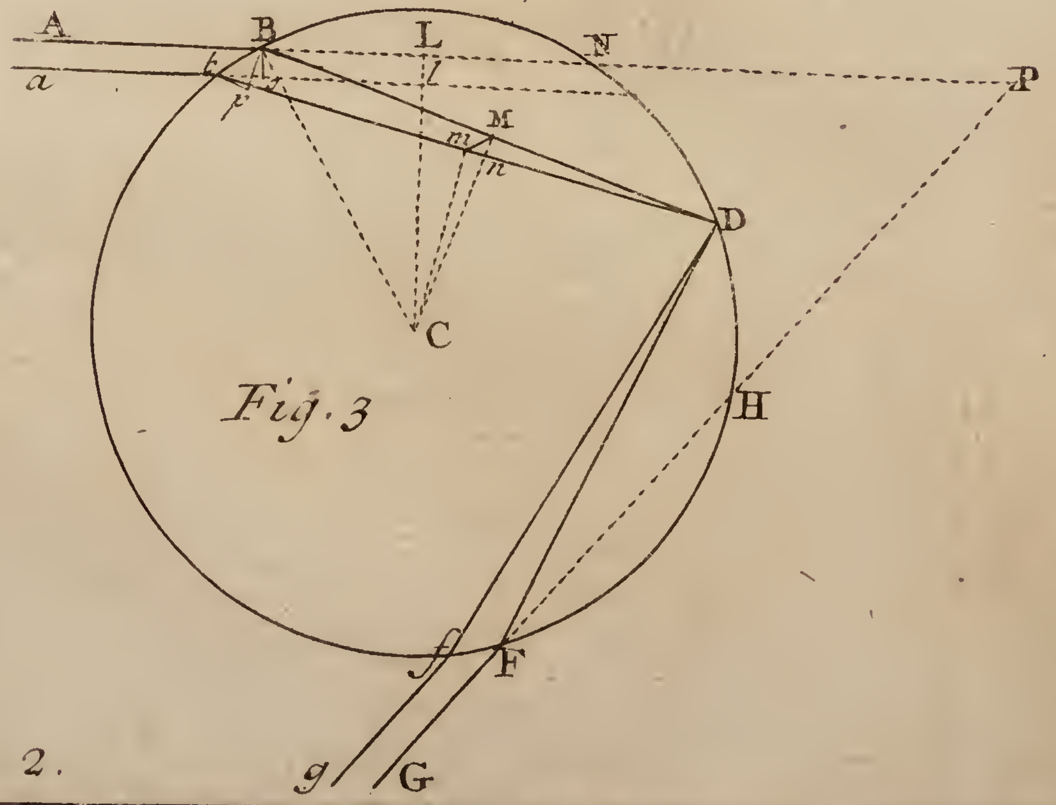

A
B
L
N
a
t
l
P
p
m
M
n
D
C
H
f
F
g
G

Fig. 3

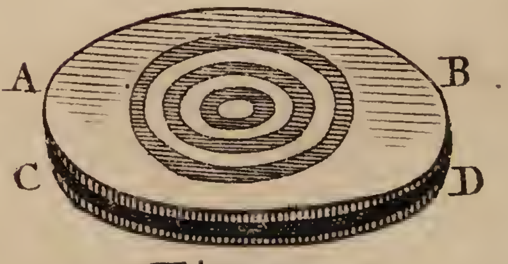


Fig. 6

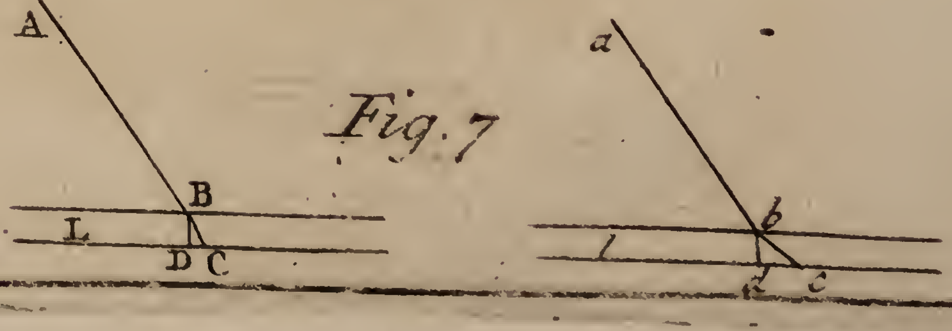

A
B
L
D
C
a
b
l
d
c

Fig. 7

Experiment 3.] Take two Bodies of any Kind, the one red, the other blue; let them be enlighten'd ſucceſſively in a dark Place by the Colours of the colour'd Image, which is made by the Refraction of the Priſm; every one of the Colours will be reflected by both; but the red Rays are copiouſly reflected from the red Body, whilſt the blue Body reflects but few of them, which plainly appears by comparing both Bodies, when they are enlighten'd by the red; the contrary may be obſerv'd in blue Colours, which are copiouſly reflected from the blue Body, whilſt only a few are reflected from the red one.

The Rays which are not reflected from a
Body, penetrate into it, and there ſuffer innu-
merable Reflexions and Refractions, as we have
explain'd between N° 842, and 843; till at
length they unite themſelves to the Particles of
the Body itſelf.* Therefore *a Body grows hot ſo* *546
much the ſooner, as it reflects Light leſs copiouſly. 908
For which reaſon *a white Body*, which reflects al- 909
moſt all the Rays with which it is enlighten'd,* *870
heats the ſloweſt, whilſt a black Body, into which
almoſt all the Rays penetrate, becauſe only few
are reflected,* *acquires Heat ſooner than any other.* *845

To determine that Conſtitution of the Sur-
faces of Bodies, upon which their Colour de-
pends, we muſt take Notice of the ſmalleſt Par-
ticles, of which theſe Surfaces are made up;
theſe Particles are tranſparent*, and are ſepa- *841
rated by a Medium of a different Denſity from
the Particles themſelves;* they are alſo thin, *843
otherwiſe the Surface wou'd as it were be co-
ver'd by a tranſparent Body,* and the Colour *843
wou'd depend upon the Particles under theſe.
Therefore in the Surface of every colour'd Body
there are innumerable ſmall thin Plates; but by

leſſening the Plate, keeping the ſame Thickneſs, its Properties, as to the Reflexion of Light, are not chang'd; for the leaſt Plate, in reſpect of the Rays of Light, is very large: Wherefore what has been demonſtrated in the preceding *Chap.* may be applied to theſe Plates in the Surfaces of Bodies. From whence we deduce the following Concluſions.

910 *The Colour of a Body depends upon the Thickneſs,*
* 890, *and Denſity of the Parts of the Body, which are in*
911 *the Surface, between the Pores of the Body.**
* 898, *The Colour is ſo much the more vivid and homo-*
899,
900. *geneous, as the Parts are thinner.**

912 Cæteris paribus, *the aforeſaid Parts are of the*
* 896, *greateſt Thickneſs when the Body is red, and of the*
861 *leaſt, when violet.**

913 *The Parts of Bodies are much denſer than the*
* 902, *Medium contain'd in their Interſtices.**
903,
904. *This Denſity is leſs in* the Tails of Peacocks and
914 in ſome Silks, and in general in all *Bodies, whoſe*
* 901, *Colour varies according to the different Situation of the*
903 *Eye.**

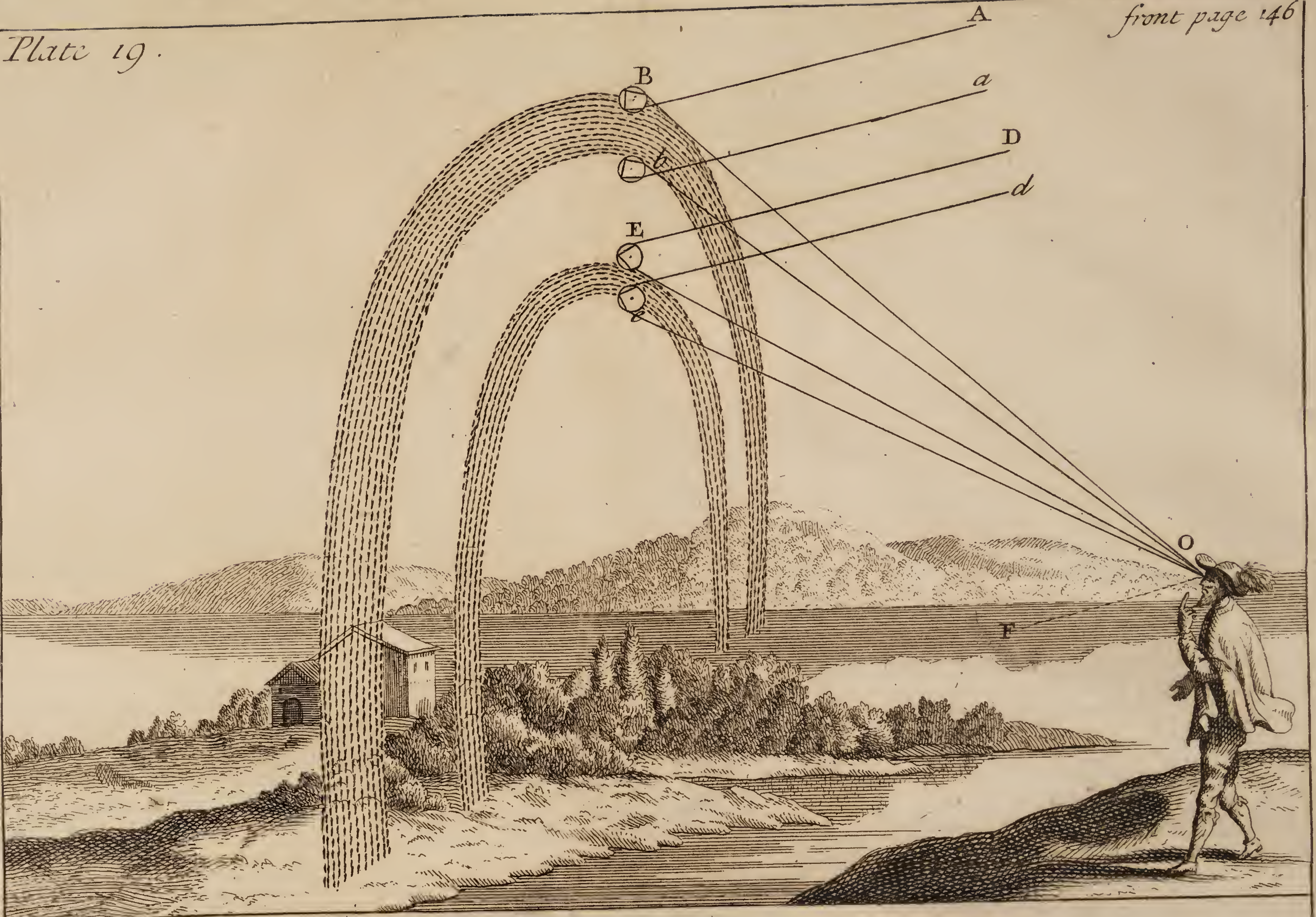
915 *The Colour of a Body is more obſcure and darker,*
* 891 *when a denſer Medium enters its Pores;** for then
the Parts upon which its Colour depends, are
ſurrounded by a denſer Medium than before.

We experience this in all Bodies which are thoroughly penetrated by Water and Oil: When the Bodies are dry, they recover their former Colour, unleſs in ſome Caſes, in which, ſome Parts are carried away by the Action of the Water or Oil, or when ſome Parts of the Water or Oil are ſo united with the Parts of the Body, as to change the Thickneſs of the Plates.

From ſuch a Cauſe are deduc'd the Changes
in the Colours of ſome Liquors, by their being
916 mix'd with others. *Often the ſaline Particles ſwim-*
ming in one Liquid, unite themſelves to the ſaline

Plate 19.

front page 146


A
a
B
b
D
d
E
e
O
F

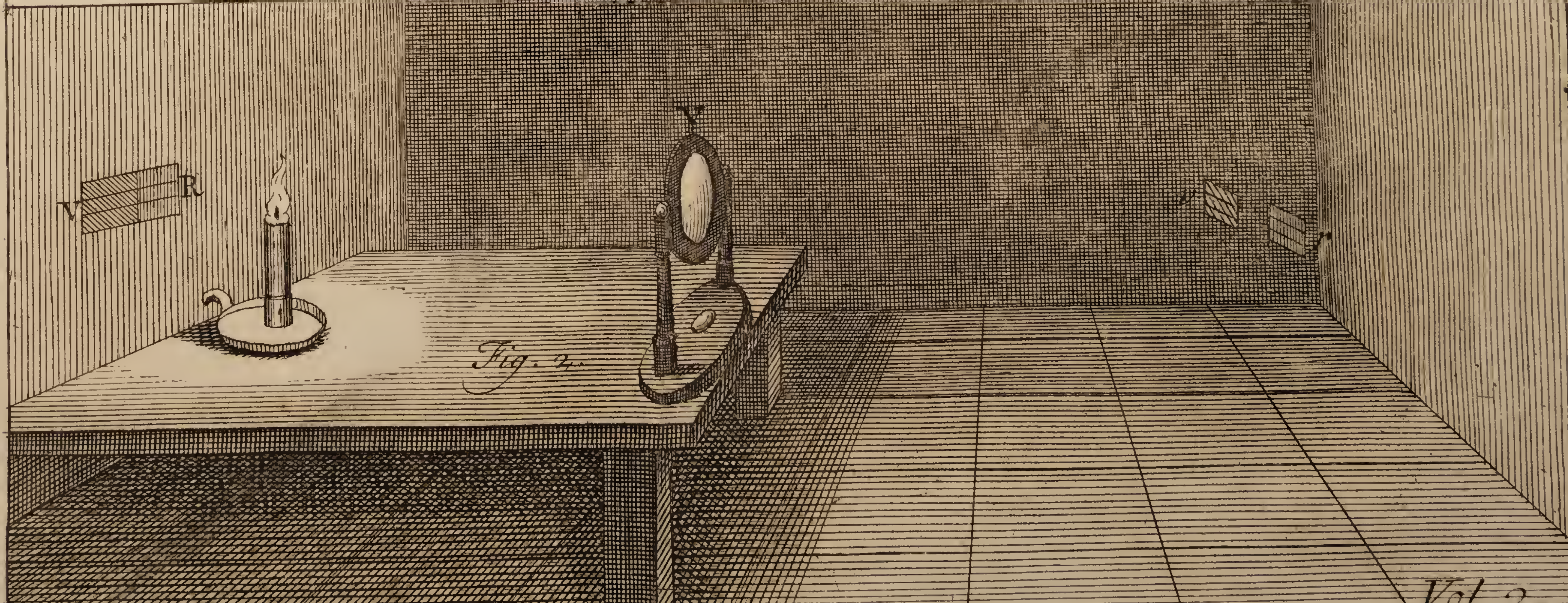


Fig. 2.

Vol 2.

Particles ſwimming in another; or *the united Particles are ſeparated by the Actions of others that are ſuper-added; on all which Accounts* the Thickneſs of the Particles *is chang'd*, and together with it *the Colour of the Liquids.** *888

Sometimes the Colour of a Liquid is different, when ſeen by reflected Rays, from what it is when ſeen by tranſmitted ones: We have ſhewn before whence this ariſes.* 917 *887

Experiment 4.] An Infuſion of *Lignum Nephriticum*, that is not too much ting'd, appears blue by reflected Rays, but yellow, if the Phiol which contains the Infuſion be plac'd between the Light and the Eye.

Experiment 5.] If you pour Spirit of Vinegar into the Infuſion of *Lignum Nephriticum*, it will appear yellow in any Poſition whatever.

In this Caſe the Thickneſs of the Particles is chang'd, and the Rays that were tranſmitted thro' every one of them are now intercepted; but tho' the Liquor is plac'd between the Eye and the Light, it is ſeen by reflected Rays; for we may eaſily conceive that ſuch Rays come to the Eye by the various Reflexions which the Light undergoes in the Liquid. But this Colour only is ſenſible, becauſe the Rays cannot penetrate directly thro' the Liquid.

From this we may deduce the reaſon, why *a colour'd Liquid, in a Glaſs of the Figure of an inverted Cone, if it be plac'd between the Eye and the Light, appears of a different Colour, in different Parts of the Veſſel*; in the lower Part all the Rays which are tranſmitted thro' the Particles are not intercepted; then they are more and more intercepted, according as there is a greater Quantity of the Liquid between the Eye and the Light; till at 918 length they come to be all intercepted; and only thoſe Rays which are reflected by the Particles penetrate the liquid; in which Caſe the Colour coincides with the Colour of the Liquid ſeen by the reflected Rays.

919 *Clouds* often *appear very beautifully colour'd*; they conſiſt of aqueous Particles, between which Air is interſpers'd; therefore, *according to the various*
920 *Thickneſs of thoſe aqueous Particles*, the Cloud will
888 be of a different Colour.

The End of the Third Book.

Mathematical ELEMENTS
OF
Natural Philoſophy,
Confirm'd by
EXPERIMENTS.

BOOK IV.

PART I. *Of the Syſtem of the World.*

CHAP. I.
A general Idea of the Planetary Syſtem.

* HE who attentively conſiders that Space can be terminated by no Bounds, will ſcarce be able to deny, that the Supreme Almighty Intelligence, has every where manifeſted the ſame Wiſdom which He has ſhewn to the Inhabitants of the Earth in a ſmall *15

Compaſs. What I here call a ſmall Compaſs, immenſly exceeds our Comprehenſion; yet it is but ſmall, compar'd with infinite Space.

921 *Our Earth, with ſixteen other Bodies* (for we have no Knowledge of any more) *moves in a determinate Space*; neither do theſe Bodies recede from, or come nearer to one another beyond their ſet Bounds; and their Motions are perform'd according to unchangeable Laws.

DEFINITION I.

922 *This Collection of ſeventeen Bodies is call'd the* Planetary Syſtem.

The whole Art of *Aſtronomy* is almoſt employ'd concerning theſe alone; and theſe will be chiefly my Subject in this Work: The other Bodies that conſtitute the Univerſe are too far diſtant from us; for their Motions (if they are mov'd) to fall under our Obſervation: Of theſe only the lucid Bodies can be perceiv'd by us; and of thoſe only the more remarkable ones, and which are leſs diſtant from us than the reſt; even moſt of ſuch as are ſeen by the Teleſcope are inviſible to the naked Eye.

DEFINITION II.

923 All theſe Bodies are call'd *fix'd Stars.*

They are call'd fix'd, becauſe as far as can be perceiv'd, they keep the ſame Poſition with reſpect to one another: We muſt take Notice of ſomething peculiar concerning theſe hereafter.

924 But as to the planetary Syſtem: *In this* we have ſaid *there are* ſeventeen *Bodies, which are all ſpherical: One only ſhines by its own Light, the reſt are opaque, and are viſible only by the Light which they borrow from that.*

925 *The Sun is that lucid Body, and far the greateſt of all in the planetary Syſtem; it is quieſcent in the middle*

dle of it, at leaſt is agitated by a very ſmall Motion.

DEFINITION III.

The other ſixteen are call'd *Planets.* 926

Theſe are divided into two Claſſes ; ſix are call'd the Primary Planets ; *ten are call'd the* Secondary Planets. When we ſpeak of the Planets without any Diſtinction, we always underſtand the Primary ones.

The Primary Planets move round the Sun, and are carried at different Diſtances from it, in Curves that return into themſelves. 927

A Secondary Planet revolves round a primary one, and accompanies it in its Motion round the Sun. 928

The Planets in their Motions deſcribe Elliptic Lines, not much different from Circles. *And* all *thoſe* Lines *are fix'd*, at leaſt, there is but a ſmall Change to be obſerv'd in a long Time, in their Situation. 929

Plate XXIV. *Fig.* 3.] An Elliptic Line is form'd, if a Thread, whoſe Extremities are fix'd in the two Points F and *f*, is mov'd, remaining ſtretch'd ; as is to be ſeen in this Figure, in which the Thread is repreſented at F *d f*, F E *f*, F B *f*. The Points F, *f* are call'd the Foci ; the Line A *a*, which paſſes thro' them, and is terminated on each Side by the Circumference of the Ellipſe, is call'd the *greater Axis* ; and it is the greateſt Line that can be drawn in the Ellipſis. The middle Point E of the Axis, is the Center of the Ellipſe ; and the *leſſer Axis* D *d* falls perpendicularly thro' this Point upon the *greater Axis.* 930

The Orbits of all the Primary Planets are in ſuch a Poſition, that one of their Foci falls in with their Center of the Sun; let the Ellipſe A D *a d* repreſent 931 repreſent the Orbit of a Planet, F will be the Center of the Sun.

DEFINITION IV.

932 *The Diſtance between the Center of the Sun, and the Center of the Orbit, is call'd* the Excentricity of the Planet; as F C.

933 *In every Revolution the Planet approaches once to the Sun, and once recedes from it*; and at its greateſt Diſtance is at *a*, the Extremity of the greater Axis of the Orbit, and at its leaſt Diſtance, in the oppoſite Extremity A.

DEFINITION V.

934 *That Diſtance of the Planet from the Sun is called the* Mean Diſtance, *which is equally different from the greateſt and the leaſt.* At this Diſtance the Planet is in the Extremities D, *d*, of the ſmaller Axis.

DEFINITION VI.

935 *The Point of the Orbit, in which the Planet is at its greateſt Diſtance from the Sun, is call'd* the Aphelium; as *a*.

DEFINITION VII.

936 *The Point of the Orbit, in which the Planet is at its leaſt Diſtance from the Sun is call'd* the Perihelium.

DEFINITION VIII.

937 Theſe Points are commonly call'd the *Auges* or *Apſides.*

DEFINITION IX.

938 *The Line which joins the Apſides*, that is, the greater Axis of the Orbit, *is call'd*, the Line of the Apſides.

Every Orbit is in a Plane which paſſes thro' the Center of the Sun. 939

DEFINITION X.

The Plane of the Orbit of the Earth is call'd the Plane of the Ecliptic. 940

This Plane is to be continued every way; and *Aſtronomers* conſider the Poſition of the Planes of the other Orbits with reſpect to this.

DEFINITION XI.

The Points in which the other Orbits cut the Plane of the Ecliptick are call'd the Nodes. 941

DEFINITION XII.

The Line which joins the Nodes of any Orbit, that is, the common Section of the Plane of the Orbit with the Plane of the Ecliptic, *is call'd* the Line of Nodes. 942

A Planet is not carried with an equal Celerity in 943
all the Points of its Orbit; the leſs it is diſtant from 944
the Sun, the ſwifter is its Motion; and the Times in which the ſeveral Arcs of its Orbit are run thro', are to one another as the Area's form'd by Lines drawn from the Planet to the Center of the Sun; the Arcs A B and *a* E are run thro' in Times, which are to one another as the Area's of the mix'd Triangles A F B, *a* F E.

All the Planets are carried the ſame way, and their Motion in their Orbits is contrary to that Motion which we obſerve daily in all the Cæleſtial Bodies, by which in one Day they ſeem to be carried round the Earth; of which hereafter. 945

DEFINITION XIII.

A Motion, ſuch as is that of the Planets in their Orbits, is ſaid to be in Conſequentia, and Direct. 946

DEFI-

Definition XIV.

947 *The contrary Motion is call'd a Motion* in Antecedentia; *and ſometimes* Retrograde.

948 *The more diſtant the Planets are from the Sun, the ſlower they move in their Orbits*; ſo that the periodical Times of the moſt diſtant ones are greater, both becauſe they have a greater Orbit to run thro', and a ſlower Motion.

Definition XV.

949 *The Line which paſſes thro' the Center of the Planet, and about which it moves, is call'd* the Axis of the Planet.

950 *The Planets*, at leaſt moſt of them, *and the Sun itſelf move round their Axes:* There are Two, of which, in this reſpect, we cou'd make no Obſervations, but which in all Probability have this Motion.

951 *This Motion* agrees or conſpires with the Motions of the Planets in their Orbits, that is, it *is* in Conſequentia.

952 *The Axes* themſelves *are mov'd by a parallel Motion*, ſo that all the Points of the Axis of a Planet deſcribe equal and ſimilar Lines.

Definition XVI.

953 *The Extremities of the Axis are call'd* the Poles of the Planet.

954 *Plate* XX. *Fig.* 1.] Aſtronomers compare together accurately enough the Diſtances of the Planets from the Sun, to give us an Idea of the whole Syſtem. The Dimenſions of the Orbs are repreſented in this Scheme, in which the Points N N ſhew the Nodes of each Orb.

955 Neverthele*ſ*s *we cannot compare the Dimenſions of this Syſtem with any that we know upon the Surface of the Earth*; for no Aſtronomer will aſſert,

that the Obſervations made concerning ſuch a Compariſon, are free from Error.

956 But that the ſeveral Parts of the Syſtem may be compar'd together; we ſuppoſe the middle Diſtance of the Earth from the Sun divided into 1000 equal Parts, which we make uſe of in meaſuring the other Dimenſions.

957 The Sun ☉, as was ſaid before, is agitated by a ſmall Motion in the middle of the Syſtem; it moves round its Axis in the Space of 25 Days: And its Axis is inclin'd to the Plane of the Ecliptic, making an Angle of 87 Deg. 30 Min.

958 *Mercury* ☿, is the leaſt diſtant from the Sun of any of the Planets; its Mean Diſtance from the Sun is 387, its Excentricity 80, the Inclination of its Orbit, that is, the Angle form'd by the Plane of its Orbit with the Plane of the Ecliptic is 6 Deg. 52 Min. it performs its Revolution round the Sun in 87 Days, 23 Hours.

959 The next is *Venus* ♀, whoſe Diſtance from the Sun is 723, its Excentricity 5, the Inclination of its Orbit 3 Deg. 23 Min. It performs its Periodical Motion in 224 Days, 17 Hours; and its Motion round its Axis is perform'd in 23 Hours.

960 The third Planet, in order from the Sun, is our Earth ⊖; its Mean Diſtance from the Sun is 1000, its Excentricity 169: It is mov'd in the Plane of the Ecliptick; its Periodical Time is 365 Days, 5 Hours, 51 Min. and the Motion about its Axis is perform'd in 23 Hours, 56 Min. 4 Seconds. Its Axis makes an Angle with the Plane of the Ecliptic of 66 Deg. 31 Min.

961 The Mean Diſtance of *Mars* ♂ from the Sun is 1524, its Excentricity 141, the Inclination of its Orbit 1 Deg. 52 Min. Its Periodical Time 686 Days, 23 Hours. Its Revolution

about its Axis is perform'd in 24 Hours, 40 Min.

962 *Jupiter* ♃, the biggeſt of all the Planets is diſtant from the Sun, at a Mean Diſtance 5201, its Excentricity 250. The Inclination of its Orbit 1 Deg. 20 Min. The Periodical Time 4332 Days, 12 Hours. And its Revolution about its Axis in 9 Hours and 56 Min.

963 The Mean Diſtance of *Saturn* ♄, the moſt diſtant Planet from the Sun is 9538, its Excentricity 547; the Inclination of its Orbit 2 Deg. 30 Min. The periodical Time 10759 Days, 7 Hours. It is encompaſs'd with a Ring which does not touch the Planet, but never leaves it: This Ring is not viſible without a Teleſcope.

The Mean Diſtance being given, if you add the Excentricity, you will have the greateſt Diſtance; but if you ſubſtract the Excentricity from the mean Diſtance, you will have the leaſt Diſtance.* * 836

964 The three Planets, *Mars*, *Jupiter*, and *Saturn*, which are more diſtant from the Sun than the Earth, are call'd the *Superior Planets*; *Venus* and *Mercury* are call'd the *Inferior ones*.

965 *Of the Primary Planets, three are accompanied by Secondary ones.*

Five Planets, call'd Satellites, move about *Saturn*; four about *Jupiter*; one about the Earth, (*viz.*) the Moon.

The ſecondary Planets, except the Moon, are not viſible to the naked Eye.

966 *The Satellites, by Lines drawn to the Center of the Primary Planets, deſcribe Area's about them, proportional to the Times*; as has been ſaid of the Primary Planets with reſpect to the Center of the Sun.* * 944

The Moon moves about the Earth in an Ellipſe, 967,
one of whoſe Foci is in the Center of the Earth, from 968,
which the mean Diſtance of the Moon is 60 969,
Semidiameters of the Earth and a half: *Its Ex-*
centricity is liable to change; the Mean one is of
3 Semidiameters and a third. The Plane *of its*
Orbit forms an Angle with the Plane of the
Ecliptick of 5 Deg. *but this Inclination is not con-* 970
ſtant, or always the ſame. In the Motion of the Moon
round the Earth, neither the Line of the Nodes, nor
the Line of the Apſides is carried in a parallel Mo-
tion; but the *Line of the Nodes* Weſtward, or in
Antecedentia; *the Lines of the Apſides* Eaſtward, or
in *Conſequentia*; the firſt performs its Revolution
in about 9 Years, the ſecond in 19. The peri-
odical Time of the Moon's Motion about the
Earth is 27 Days and about 7 Hours; and it is
turn'd about its own Axis exactly in the ſame
Time.

971 *Plate* XX. *Fig.* 2.] The Firſt or inmoſt of the Satellites of *Jupiter*, is diſtant from *Jupiter*'s Center $2\frac{5}{6}$ Diameters of *Jupiter*: It is mov'd round *Jupiter* in one Day, 18 Hours, 28 Min.

The Diſtance of the Second is 4 and an half Diameters of *Jupiter*: Its Periodical Time is 13 Hours, 18 Min.

The Diſtance of the Third is $7\frac{1}{6}$ Diameters; its Periodical Time 7 Days, 4 Hours.

The Fourth is diſtant $12\frac{2}{3}$ Diameters: It performs its Motion in 16 Days, 18 Hours, 5 Min.

972 *Plate* XX. *Fig.* 3.] The Firſt or inmoſt Satellite of *Saturn* is diſtant from *Saturn*'s Center $\frac{39}{40}$ of a Diameter of the Ring: Its Periodical Time is 1 Day, 21 Hours, 18 Min.

The Diſtance of the Second is $1\frac{1}{4}$ Diameter of the Ring: Its Periodical Time is 2 Days, 17 Hours, 41 Min.

The Diſtance of the Third is 1¾ Diameter of the Ring: Its Periodical Motion is 4 Days, 13 Hours, 47 Min.

The Diſtance of the Fourth is 4 Diameters of the Ring, its Periodical Time 15 Days, 22 Hours, 41 Min.

The Diſtance of the Fifth is 12 Diameters of the Ring; its Periodical Time is 79 Days, 7 Hours, 53 Min.

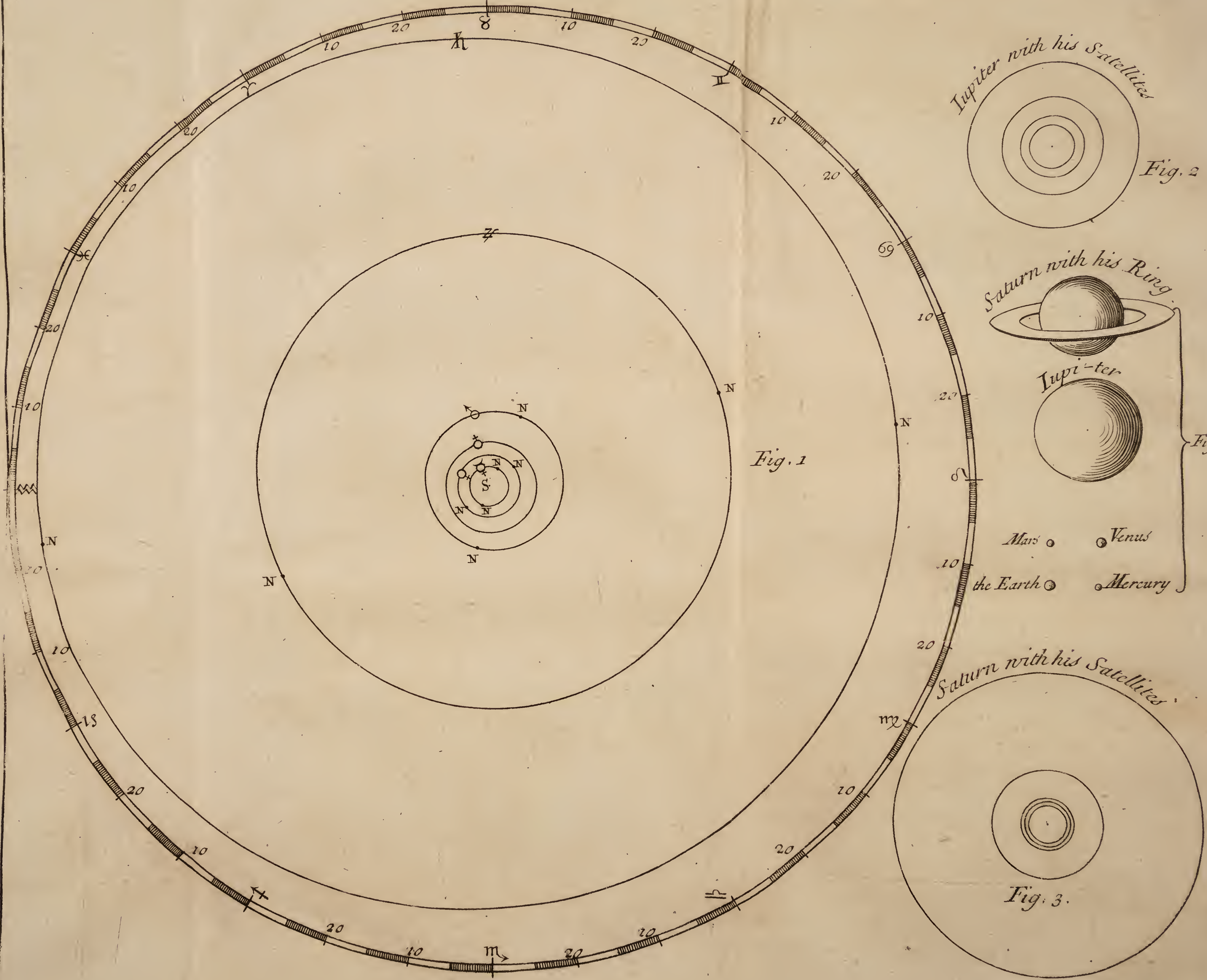
973 Concerning the Motion of theſe, as alſo of the Satellites of *Jupiter* about their Axes, we can hitherto determine nothing certain from Aſtronomical Obſervations.

If we take Notice of the Diſtances and Periodical Times of the Planets, we ſhall find that the following Rule holds good in our Syſtem, wherever ſeveral Bodies are mov'd round the ſame Point, that is, *about the* Sun, Saturn, *and* Jupiter; 974 (*viz.*) *the Squares of the Periodical Times are to one another, as the Cubes of the Mean Diſtances from the Center.*

975 *Plate* XX. *Fig.* 4.] To give a Notion of the Dimenſions of the Bodies themſelves in our Syſtem, we have contriv'd the fourth Figure in which all the primary Planets, and *Saturn*'s Ring, are deſcrib'd, according to their Dimenſions; the Sun, whoſe Magnitude exceeds all the reſt, is repreſented by the greateſt Circle (*Fig* 1.) that is, the Circle which terminates the Figure.

These Dimenſions repreſent the Proportions of the Bodies one to another exactly enough, if you except the Earth, which, for the Reaſon already mention'd,* cannot be ſo compar'd with *955 the other Bodies, as to leave no room to doubt what Proportion it bears to them.

976 Yet *the Earth's Diameter may be meaſur'd*, and contains 3400669 Perches, each of which is equal to 12 *Rhynland* Feet; but altho' the Diameters of the other


♉
♄
10
20
♊
♈
♓
♋
♃
N
S
Fig. 1
♌
♒
♑
♐
♏
♎
♍
Jupiter with his Satellites
Fig. 2
Saturn with his Ring
Jupi-ter
Fig. 4.
Mars
Venus
the Earth
Mercury
Saturn with his Satellites
Fig. 3.

other Planets may be compar'd together, and with the Sun's Diameter, yet it can't be determin'd how many Feet they contain, till after Obſervations ſhall be made at a proper Time hereafter.

Of the Bodies that make up the Planetary Syſtem, *the Moon only can be compar'd to the Earth*; its Diameter being to the Diameter of the Moon, as 40 to 11. 977

The other ſecondary Planets are not meaſur'd by Aſtronomers, but it can't be doubted, but that ſome of them are bigger than the Earth. 978

Beſides the Bodies already mention'd, there are others in the Planetary Syſtem, which are viſible for a Time, as they come near the Sun, and then recede from it, and become inviſible; they are call'd *Comets.* They *appear moſt commonly with Tails, and the Tail is always turn'd from the Sun*; *in their Motion they deſcribe Areas, by Lines drawn to the Center of the Sun, proportional to the Times*, as has been ſaid of the Planets.* 979 980 *944 966

As to Comets, it is probable that they move in elliptic Orbits that are very excentric; ſo that they are inviſible, when they are in that Part of the Orbit which is moſt diſtant from the Sun; which is deduc'd from the Periods of ſome of them, that have been obſerv'd to be pretty regular: And it is plain from Obſervations, that *ſome have deſcrib'd in their Motion Portions of very excentric Eclipſes, in one of whoſe Foci was the Center of the Sun.* 981 982

The Notion that we have hitherto given of the Planetary Syſtem, is founded upon Aſtronomical Obſervations; and what we have already ſaid admits of no Diſpute among Aſtronomers, if we except what relates to the Elliptic Line and the Motion of the Earth.

Some affirm that the Orbits of the Planets are not Elliptic, but that in their Motion they deſcribe another Oval: *Kepler* has deduc'd from *Tycho Brahé*'s Obſervations, that theſe Lines are Elliptic; and we ſhall ſhew in the following Part, that no other Curves can be deſcrib'd by the Planets.

Thoſe that ſay the Earth is at reſt, have no Aſtronomical or Phyſical Argument for a Foundation of their Opinion; that is, don't reaſon from *Phænomena*: Neglecting the Simplicity of the Syſtem, and the Analogy of the Motions, they aſſert that their Opinion is not contrary to Obſervations; in which they err, as we ſhall ſhew in the following Part.

CHAP. II.

Concerning the apparent Motion.

WHOEVER, after having read the former Chapter, looks upon the Heavens, will ſcarcely believe, that he beholds the Syſtem which is explain'd there; and a more exact Conſideration of the heavenly Motions will encreaſe his Doubt. No wonder, *ſince we can obſerve very little in the Heavens but falſe Appearances.* 983

The common Obſerver of the Heavens, is a Spectator, who thinking himſelf to be at reſt, is carried about by various Motions, and beholds Bodies, concerning whoſe Diſtance and Magnitude he makes falſe Judgments. The true Syſtem of the World was unknown for many Ages, even to the moſt exact Obſervers of the Heavens.

But we muſt explain how all Things which are obſerv'd in the heavenly Bodies, have Place in the Syſtem that has been explain'd, in reſpect of a Spectator upon the Earth; that is, we ſhall deduce the Appearances from the True Motions. Which cannot be done, unleſs we firſt lay down ſome general Things concerning the apparent Motion in general.

It is certain, that we have no Art, by which we can diſcover the true Motion, only the relative Motion can be perceiv'd by the Senſes; and it is that only concerning which we treated in the former Chapter: Who can reaſonably affirm or deny, that all the Bodies which are known to us, are not carried in a common Motion thro' the immenſe Spaces?

The Relative Motion is to be diſtinguiſh'd from the Apparent one; for the apparent Motion is the Change which appears to be in the Situation of the Bodies, and depends upon the Change of the Picture in the bottom of the Eye; for Objects have the ſame apparent Relation to one another, as their Repreſentations have in the Eye; for they are ſeen as they are painted in the Eye;* and the Change in that Picture from the Motion of the Bodies, moſt commonly differs from the Change of the Relation between the Bodies themſelves; as follows from the Formation of that Picture. 985 *716

The Heavens are nothing but an immenſe Space, which cannot be ſeen, and wou'd appear black,* if innumerable Rays of Light flowing from the heavenly Bodies did not continually penetrate our Atmoſphere. Moſt of them come to us from the Bodies in right Lines, yet a great many ſuffer various Reflexions in the Atmoſphere, and enlighten the whole Atmoſphere; which is the Reaſon that in the Day, Bodies are enlighten'd, 986 *845 en'd, even without the Reflexion of the Clouds, to which the Rays of the Sun cannot come directly.

Theſe Rays are heterogeneous and white; for there are Bodies enlighten'd by theſe Rays which appear white: And theſe Bodies ſeen through Priſms, at the Extremities, are ting'd with Colours, which does not happen in an homogeneous
874 Colour; alſo a Circle of white Paper, of half an Inch Diameter, being put upon black Cloth, if it is enlighten'd by theſe Rays, it will appear
861 oblong thro' the Priſm; and the ſame Colours which are obſerv'd in the Rays of the Sun, are ſeen here in the ſame Manner; all which Things wou'd not happen, if the Air, as many think, was a blue Liquid; that is, thro' which only the Sun's blue Rays, at leaſt moſtly ſuch, paſs.

987 *When we look at the black Sky, the white Rays,* beforemention'd, *enter our Eyes, whence the blue Colour of the Sky ariſes.* Becauſe we are accuſtom'd to ſee a Colour where there is a colour'd Object, we alſo refer the Colour of the Heavens to an Object; but ſince this is ſeen equally towards
988 all Parts, *we conceive a concave ſpherical Surface, in whoſe Center we are plac'd; we imagine this Surface to be opaque, and therefore diſtant from us beyond all viſible Bodies.*

When a Body is between a Plane and the Eye, of whoſe Diſtance we cannot judge, the Body appears to us to be applied to the Plane, whatſoever the Diſtance is between that and the Plane; for there is no Reaſon why the Parts of the Plane, which are painted at the Sides of the Image of the Body in the Eye, ſhou'd not appear at the ſame Diſtance with the Body.

989 Thence alſo *all the celeſtial Bodies* (of which the leaſt diſtant from us, (*viz.*) the Moon) is yet ſo remov'd, that we can give no Judgment

of its Diſtance,* *are referr'd to that imaginary Sphere above-mention'd; and they all appear equally diſtant, and ſeem to move in the Surface of a concave Sphere.* So the Moon appears to be amongſt the fix'd Stars, altho' its Diſtance bears ſcarcely any ſenſible Proportion to the Diſtance of *Saturn*; and the Diſtance even of *Saturn* itſelf is nothing, compar'd with the immenſe Diſtance of the fix'd Stars. It is no Wonder therefore, that the common People know nothing of the Magnitude of the celeſtial Bodies, and the Immenſity of the Heavens. * 732

We ſee from what has been ſaid, how the Motion of any Body being given, and the Motion of the Earth being known, the apparent Motion may be determin'd.

We have ſaid that a Sphere is imagin'd beyond the fix'd Stars, in whoſe Center is the Spectator:* The Orbit of the Earth is ſo ſmall * 988
in reſpect of the Diameter of this Sphere, that the Center of the Sphere is not ſenſibly chang'd by the Alteration of the Place of the Spectator, whilſt he is carried along with the Earth. Wherefore *in all the Points of the Earth's Surface, and at* 990
any Time, the Inhabitants of the Earth imagine the ſame Sphere, to which they refer the heavenly Bodies; and which hereafter we ſhall call *the Sphere of the fix'd Stars.*

991 These Things being laid down, *if we conceive a Line to be drawn thro' the Earth, and a Body, which being continued beyond the Body, cuts the aforeſaid Sphere; we have a Point,* to which the abovemention'd Body is referr'd, and *which is the apparent Place of that Body.*

Whilſt the Body, or the Earth, or both are mov'd, this Line is mov'd alſo, and *the apparent* 992
Motion is the Line, which is deſcrib'd amongſt the fix'd Stars by the Extremity of the Line abovemention'd,

mention'd, *which goes thro' the Earth and the Body, whoſe apparent Motion is obſerv'd.*

993 Therefore *the ſame Appearances will follow from the Earth's being mov'd out of its Place, as if the Body had been mov'd, and the ſame alſo may be deduc'd from the Motion of both.*

994 But *if the Body and the Earth be ſo mov'd, that the Line which paſſes thro' theſe Bodies be carried in a parallel Motion, the Body will ſeem to be at reſt amongſt the fix'd Stars*; becauſe in this Caſe, the Space gone through by the End of the Line amongſt the fix'd Stars, cannot exceed the Space gone thro' by the Earth; but the Line that is equal to the whole Space which the Earth can go thro', at ſo great a Diſtance as the fix'd Stars, is not ſenſible to us.

995 *From the Motion of the Earth round its Axis* there *is* alſo *produc'd an apparent Motion*, which will be eaſily deduc'd in its proper Place from the Foundation laid down in this Chapter.

That the apparent Motion differs from the relative, and is varied by the Motion of the Spectator, is what Sailors every Day obſerve.

CHAP. III.

Of the Phænomena or Appearances of the Sun from the Motion of the Earth in its Orbit.

Plate XXI. *Fig.* 1.] LET the Sun be at S, and the Earth in its Orbit at T; and let *r s* be the Sphere of the fix'd Stars; the apparent Place of the Sun will be at *s*.* *When*

*991

996 *the Earth is carried in its Orbit from* T to *t*, *the Sun ſeems to move in* Conſequentia, and to run

*992 thro' the Arc *s r*,* which meaſures the Angle *r* S *s* equal to the Angle T S *t*, ſo that the Celerity of

the apparent Motion of the Sun, depends upon
the Celerity of the angular Motion of the Earth,
with reſpect to the Center of the Sun; which
Motion encreaſes upon a double Account; on
account of the Diſtance from the Sun being leſſen'd,
and the Celerity of the Earth being encreas'd:
Both which Cauſes always concur;* *944
wherefore the Inequality of the apparent Motion of the 797
Sun is ſenſible. In a whole Revolution of the Earth, 998,
the Sun alſo ſeems to run thro' a whole Circle.

DEFINITION I.

This apparent Way of the Sun is call'd the Ecliptic Line. 999
It is the Section of the Sphere of the fix'd Stars with the Plane of the Ecliptic, ſuppos'd to be continu'd to this Sphere.

This Way is divided into 12 equal Parts, each of which contain 30 Deg. theſe Parts are call'd the Signs, and are diſtinguiſh'd by theſe Names; *Aries* ♈, *Taurus* ♉, *Gemini* ♊, *Cancer* ♋, *Leo* ♌, *Virgo* ♍, *Libra* ♎, *Scorpius* ♏, *Sagittarius* ♐, *Capricorn* ♑, *Aquarius* ♒, *Piſces* ♓. Whence theſe Parts have their Names, we ſhall explain when we treat of the fix'd Stars.

The Sun is longer in going thro' the ſix firſt Signs, 1000
than the ſix laſt, and the Difference is nine Days.

Altho' a Circle has neither Beginning nor 1001
End, yet when ſeveral Points muſt be determin'd
in it, ſome Point muſt be taken as *the Beginning*;
this *in the Ecliptic Line is the firſt Point
of* Aries; we ſhall ſhew how it may be determin'd
hereafter. It is not fix'd to one Place
amongſt the fix'd Stars; therefore *the Orbits of* 1002
the Planets, which alter ſo little, that they may
be look'd upon as unchangeable,* *don't preſerve* *929
the ſame Situation in reſpect of this Point.

DEFINITION II.

1003 *The Diſtance of the Sun from the firſt Point of* Aries, *meaſur'd in* conſequentia, *is call'd* the Sun's Longitude.

1004 *The Longitudes of the other heavenly Bodies are meaſur'd after the ſame manner in the Ecliptic; they*
1005 *are referr'd to this Line, by conceiving a great Circle to paſs thro' the Body, and cut the Ecliptic perpendicularly*; for the Point in which the Ecliptic is cut by this Circle, determines the Longitude of the Body.

DEFINITION III.

1006 *The Diſtance of a heavenly Body from the Ecliptic, is call'd its* Latitude. It is meaſur'd by an Arc of a great Circle, perpendicular to the Ecliptic, intercepted between the Body and the Ecliptic.

DEFINITION IV.

1007 *If we imagine a Line to go thro' the Center of the Sphere of the fix'd Stars, and perpendicular to the Ecliptic, the Points in which this cuts the above-mention'd Sphere, are call'd the* Poles of the Ecliptic.

DEFINITION V.

1008 *The* Zodiac *is a* Zone *which is imagin'd in the Heavens, which the Ecliptic Line cuts into two equal Parts, and which, on either ſide, is terminated by a Circle parallel to the Ecliptic Line, and eight Degrees diſtant from it.* On Account of the ſmall Inclinations of the Orbits of the Planets, and the Moon to the Plane of the Ecliptick, no Bodies
1009 of the Planetary Syſtem appear without the *Zodiac.*

DEFINITION VI.

Thoſe of them that have the ſame Longitude are ſaid to be in Conjunction. 1010

DEFINITION VII.

Thoſe whoſe Longitudes differ 180 *Deg. are ſaid to be* in Oppoſition. 1011

CHAP. IV.

Of the Phænomena of the Inferior Planets, ariſing from the Earth's, and their own Motions in their Orbits.

Plate XXI. *Fig.* 2.] LET S be the Sun, AVB*v* the Orbit of an Inferior Planet; let T be the Earth in its Orbit; and *a* v *b* Part of the Sphere of the fix'd Stars; the apparent Place of the Sun is v.* * 991

If from the Earth there be drawn to the Orbit of the Planet the Tangents TA*a*, TB*b*, it is evident that the Planet, in its apparent Motion, is never remov'd farther from the Sun, than the Diſtance v*a*, or v*b*; and that the Planet accompanies it in its apparent Motion round the Earth.

DEFINITION I.

The apparent Diſtance of the Planet from the Sun is call'd its Elongation; v*a* or v*b* is *the greateſt Elongation:* 1012 This varies upon two Accounts; (*viz.*) becauſe the Earth and the Planet both revolve in elliptic Lines.* 1013 * 929

The Planet performs its Motion ſooner than the Earth;* therefore, *in its Motion,* it *paſſes between the Earth and the Sun, and then moves beyond* 1014 * 948 *yond the Sun in reſpect of the Earth: So that it is in Conjunction with the Sun in two manners,* but *never in Oppoſition.*

That we may have an Idea of the apparent Motion of the Planet, we muſt conceive the Lines T B *b*, T S v, T A *a*, to move along with the Earth; ſo that the Points A, V, B, and *v*, whilſt the Earth performs its Revolution, may run thro' the Orbit of the Planet; but the Planet, which moves ſwifter, paſſes ſucceſſively thro' theſe Points over and over.

1015 *When* it is carried in its Orbit from V to D,
it ſeems to move amongſt the fix'd Stars from
v to *d*; in this Caſe, *the apparent Motion is in* An-
1016 tecedentia, and *the Planet is Retrograde.* In D it
is ſaid to be *Stationary*; becauſe *it appears, for*
ſome Time, in the ſame Place amongſt the fix'd Stars:
This obtains, when the Orbit of the Planet, in
the Place in which the Planet is, is ſo inclin'd
to the Orbit of the Earth, in the Place in which
the Earth is, that, if the Line *t d* be drawn pa-
rallel to the Line T D, and at a ſmall Diſtance
from it, D *d* be to T *t* as the Celerity of the Planet
in its Orbit, to the Celerity of the Earth; theſe
* 53 Lines are run thro' in the ſame Time;* and the
Line which is drawn thro' the Earth and the
Planet, is carried in a parallel Motion; for which
Reaſon the apparent Place of the Planet is not
* 994 chang'd.*

Between *d* and B the Orbit of the Planet is
more inclin'd to the Orbit of the Earth; where-
fore the Extremity of the Line paſſing thro' the
Earth and the Planet (altho' the Planet moves
1017 ſwifter than the Earth) is carried *in Conſequentia*;
towards which Part alſo *the apparent Motion of the*
* 992 *Planet is directed.** Yet ſince the apparent Mo-
tion of the Sun exceeds the apparent Motion of
the Planet, the Elongation is encreas'd, which

becomes greateſt, when the Planet is at B. Whilſt the Planet goes thro' the Arc Bv, its apparent Motion is alſo *in Conſequentia*, and exceeds the Apparent Motion of the Sun, to which it is coming, and then goes beyond it, receding from it, till it comes to A. Between A and E the Motion *in Conſequentia* is continu'd; but the Sun, whoſe apparent Motion in this Caſe is ſwifter, as has been explain'd concerning the Arc dB, comes towards the Planet, and the Elongation is diminiſh'd. At E, in the ſame 1018
Manner as at D, *the Planet* is Stationary, between E and V it is again Retrograde.

The Orbit of the Planet is inclin'd to the Plane of the Ecliptic;* therefore it *does not* *958, 959
ſeem to move in the Ecliptic Line, but ſometimes leſs, ſometimes more diſtant from it, and *appears to be carried in an irregular Curve, which ſometimes cuts the Ecliptic.*

Plate XXI. *Fig.* 3.] Let N V N be the Orbit of the Planet, whoſe Nodes are N N; let S be the Sun; **T** t the Orbit of the Earth in the Plane of the Ecliptic; the Earth **T**; the Planet V. If VA be imagin'd to paſs thro' the Planet, and to be perpendicular to the Plane of the Ecliptic, the Angle V**T**A, or rather the Arc which meaſures it, is the Latitude of the Planet:* This is call'd *the Geocentric Latitude*, to di- *1006
ſtinguiſh it from the Latitude of the Planet ſeen from the Sun, which is call'd *the Heliocentric Latitude*, and is in that Caſe the Angle V S A; here we ſpeak of the *Geocentric Latitude*, becauſe we examine the Phænomena as they appear from the Earth.

When a Planet is in the Node, it appears in the 1019
Ecliptic Line; and the Curve, which is deſcrib'd by the Planet, by its Apparent Motion in the Zodiac, cuts the Ecliptic Line; *as the Planet* 1020
recedes

recedes from the Node, its Latitude is encreas'd, which is alſo different, according to the Situation of the Earth; ſo the Planet remaining at V, the Latitude is greater if the Earth be at **T**, than if it was at *t*. Now, if the Earth remaining in its Place, we imagine the Planet to be carried from V to *v*; the Angle *v* **T** B will be leſs than the Angle V **T** A upon a double Account, from the Planet coming nearer the Node, and the Spectator being mov'd farther off.

Now, if we conſider that both the Earth and the Planet are continually mov'd, we ſhall eaſily conceive that the Latitude is chang'd every Moment from each Cauſe, which ſometimes act contrariwiſe, and ſometimes conſpire in encreaſing and diminiſhing the Latitude; whence it neceſſarily follows, that the Apparent Motion is perform'd in an irregular Curve, which, as was ſaid before, cuts the Ecliptic as often as the Planet paſſes the Node, that is, twice in each of its Revolutions; this Curve alſo does not recede from the Ecliptic, on either Side, beyond certain Limits in the Zodiac.

We diſcover alſo ſome remarkable Phænomena of the inferior Planets by means of the Teleſcope, which are owing to their Opacity.

Plate XXI. *Fig.* 4.] Let S be the Sun, **T** the Earth, A, B, C, v, D, E, V, an inferior Planet, *ex. gr. Venus* in its Orbit. This Planet ſhines with Light borrow'd from the Sun, and that Hemiſphere only which is turn'd to the Sun is enlighten'd, the other Hemiſphere is inviſible: Therefore that Part only of the enlighten'd Hemiſphere which is turn'd to the Earth, can be ſeen from it; in V the Planet cannot be ſeen; in v it wou'd appear round, if the Sun's Rays did not hinder it from being ſeen.

Going from v *the Planet continually decreaſes*; 1021 at D it has the Figure *d*; at *e* and *f* it is drawn, as it appears at E and F, and continues to decreaſe, *till it vaniſhes at* V, *and then again encreaſes ſucceſſively, changing its Figure,* 'till the whole enlighten'd Hemiſphere be turn'd towards the Earth.

When the Node is at V, or near it, *the Planet appears in the very Disk of the Sun,* and as it 1022 were apply'd to *it,* and *is obſerv'd as a black Spot which moves on the Sun's Surface*; in this Caſe, properly ſpeaking, we don't ſee the Planet, but we perceive where it intercepts the Sun's Rays.

The leſs diſtant the Planet is from the Earth, the 1023 *greater it appears,** and the more lucid; but as it * 733 comes nearer the Earth, the lucid Part that is viſible is leſs, ſo that on one Account the Light encreaſes, and on another it is diminiſh'd; *and there is a Diſtance at which the reflected Light is greateſt.*

CHAP. V.

Concerning the Phænomena of the Superior Planets, ariſing from their Motions and the Motion of the Earth in their reſpective Orbits.

THE Apparent Motions of the Superior Planets do in many Things agree with what has been explain'd in reſpect of the Inferior Planets, and in many Things diſagree. *They* 1024 *do not always accompany the Sun, but are often obſerv'd in Oppoſition*; but in their Oppoſition (as has been ſaid of the Inferior Planets) *they do not* 1025 *always ſeem to be carried in* Conſequentia, *but often appear Stationary, and often Retrograde.*

Plate

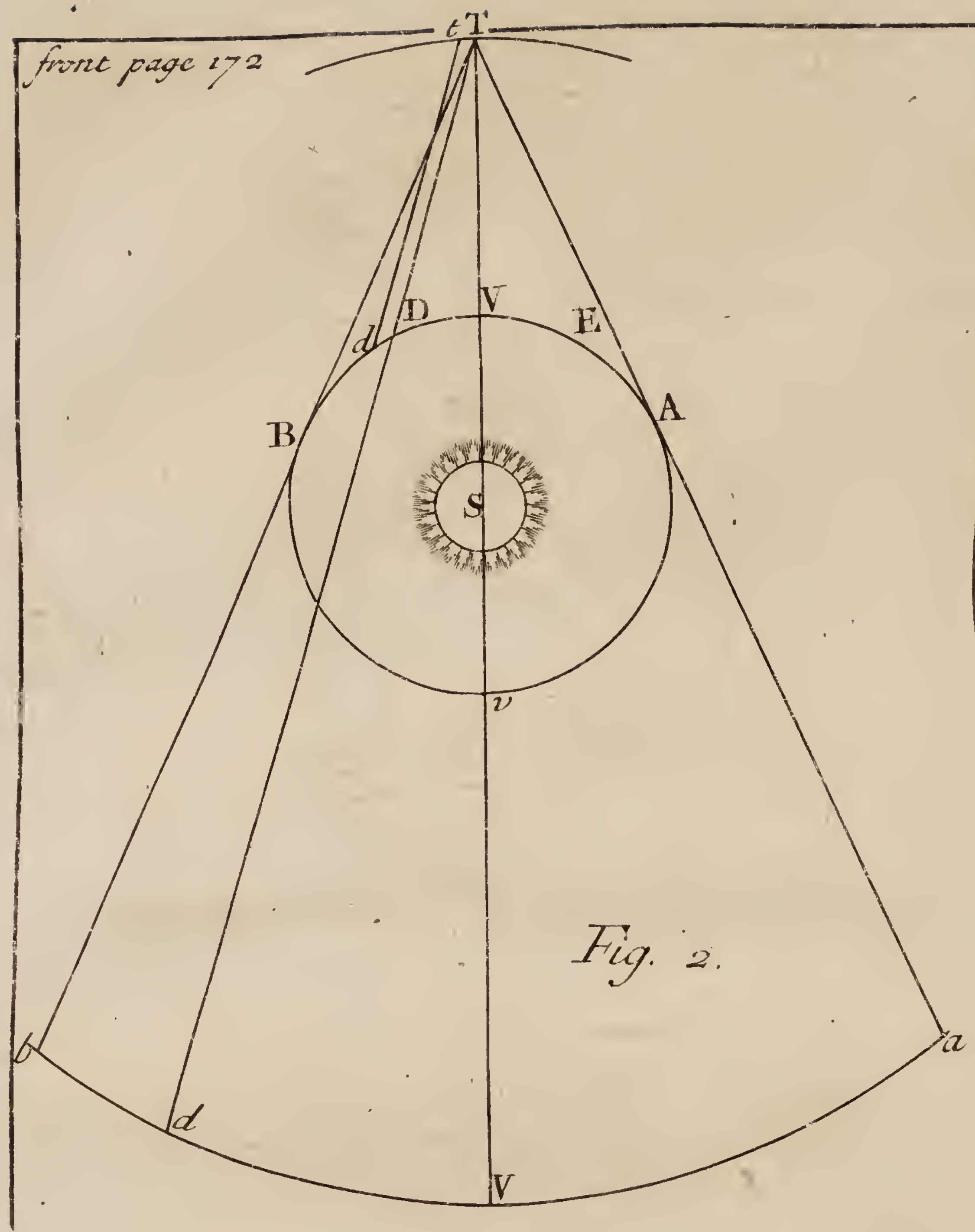
1026 *Plate* XXII. *Fig.* 1.] Let M be *a Superior*
Planet, for Example, *Mars* in its Orbit, ATHB
the Orbit of the Earth. The Periodical Time
of the Earth is ſhorter than the Periodical Time
* 948 of *Mars* *; therefore the Earth in its Motion
goes between it and the Sun; in which Caſe the
Planet *appears* at F, amongſt the fix'd Stars *oppoſite*
to the Sun. Thro' M draw the Lines B M,
A M, that touch the Earth's Orbit, which being
continued, go to G and D in the Sphere of
the fix'd Stars. Let us imagine, that whilſt the
Planet is carried about in its Orbit, thoſe Lines
are alſo moved; ſo that the Points A and B, in
which the Lines that go thro' the Planet touch
the Orbit of the Earth, perform a Revolution
in the Periodical Time of the Planet. Now
ſince the Earth revolves faſter, it paſſes thro' the
Points A and B in its Motion. In this Motion
the Apparent Place of the Planet ſeen from the
Earth, is not remov'd from the Place of the Planet
ſeen from the Sun beyond F D and F G.
Let T be ſuch a Point in the Orbit of the
Earth, that the Line *t m* being drawn, may be
parallel to T M; let T*t* be to M*m*, as the Celerity
of the Earth to the Celerity of the Planet;
in which Caſe theſe ſmall Lines are gone
* 53 thro' in the ſame Time;* in the mean Time the
* 994 Planet ſeems to be at reſt,* and is ſaid to be
Stationary. In the ſame Manner it is ſtationary
when the Earth is at H. In the Motion of the
Earth between T and H, the Planet appears to
move in *Antecedentia* from E thro' F, and is ſaid
to be Retrograde; whilſt the Earth goes thro'
the reſt of its Orbit, the Planet is direct.

1027 The Phænomena which relate to the Latitude
are like thoſe which have been explain'd in
* 10 8 reſpect to the inferior Planets.*

Jupiter

front page 172

Plate 21.



t T
D
V
E
d
B
A
S
v
b
d
V
a

Fig. 2.

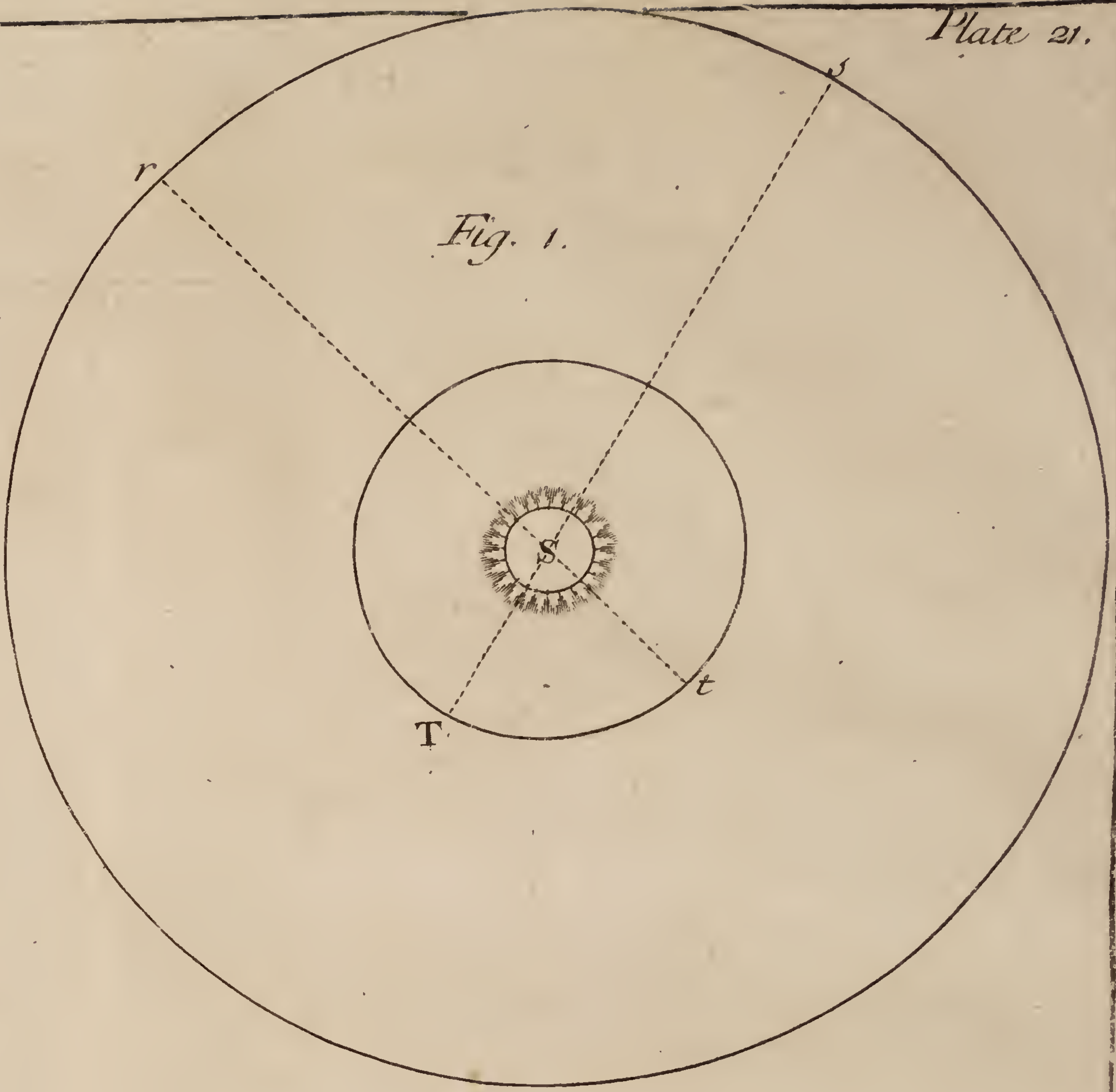


Fig. 1.

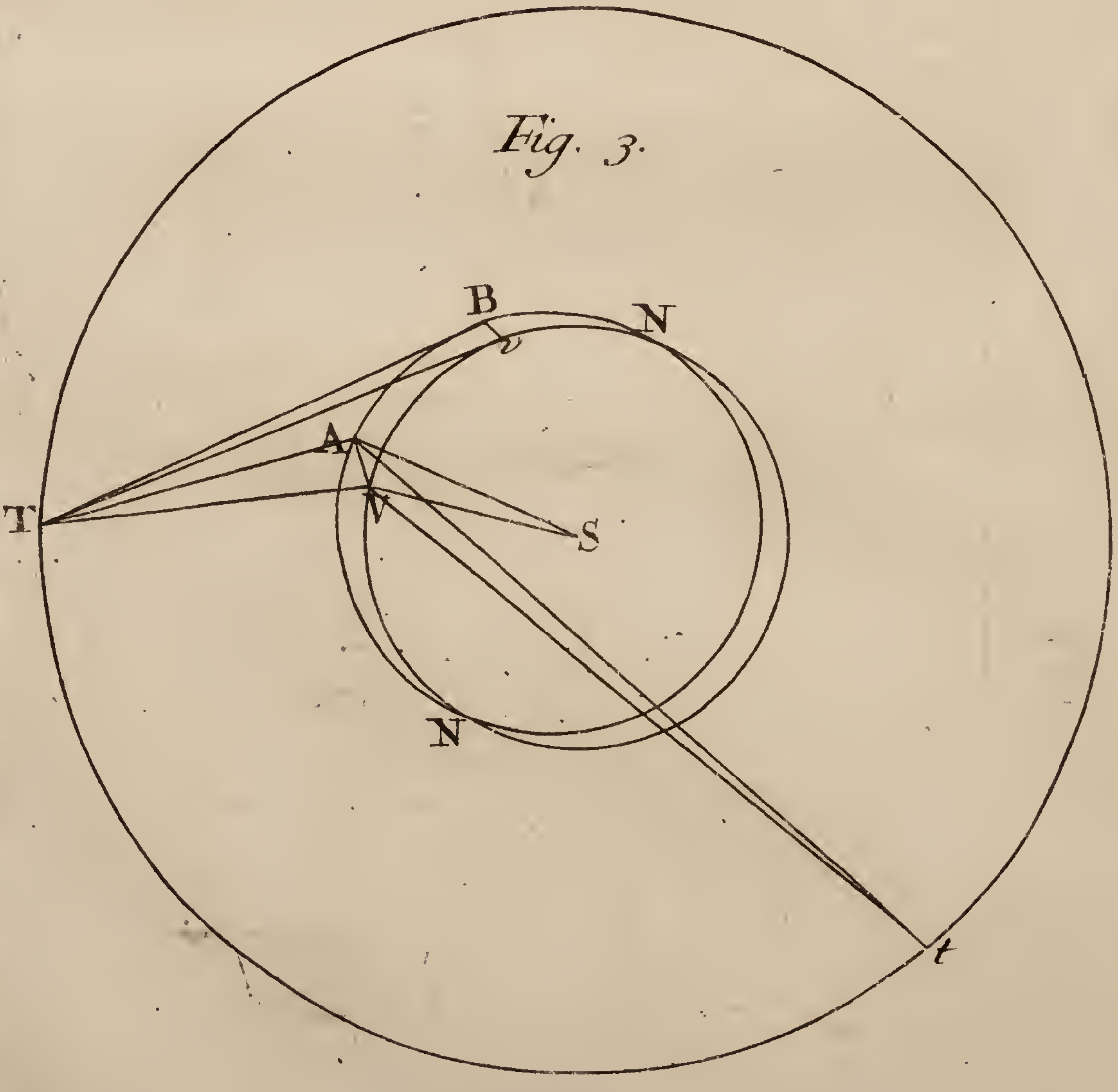
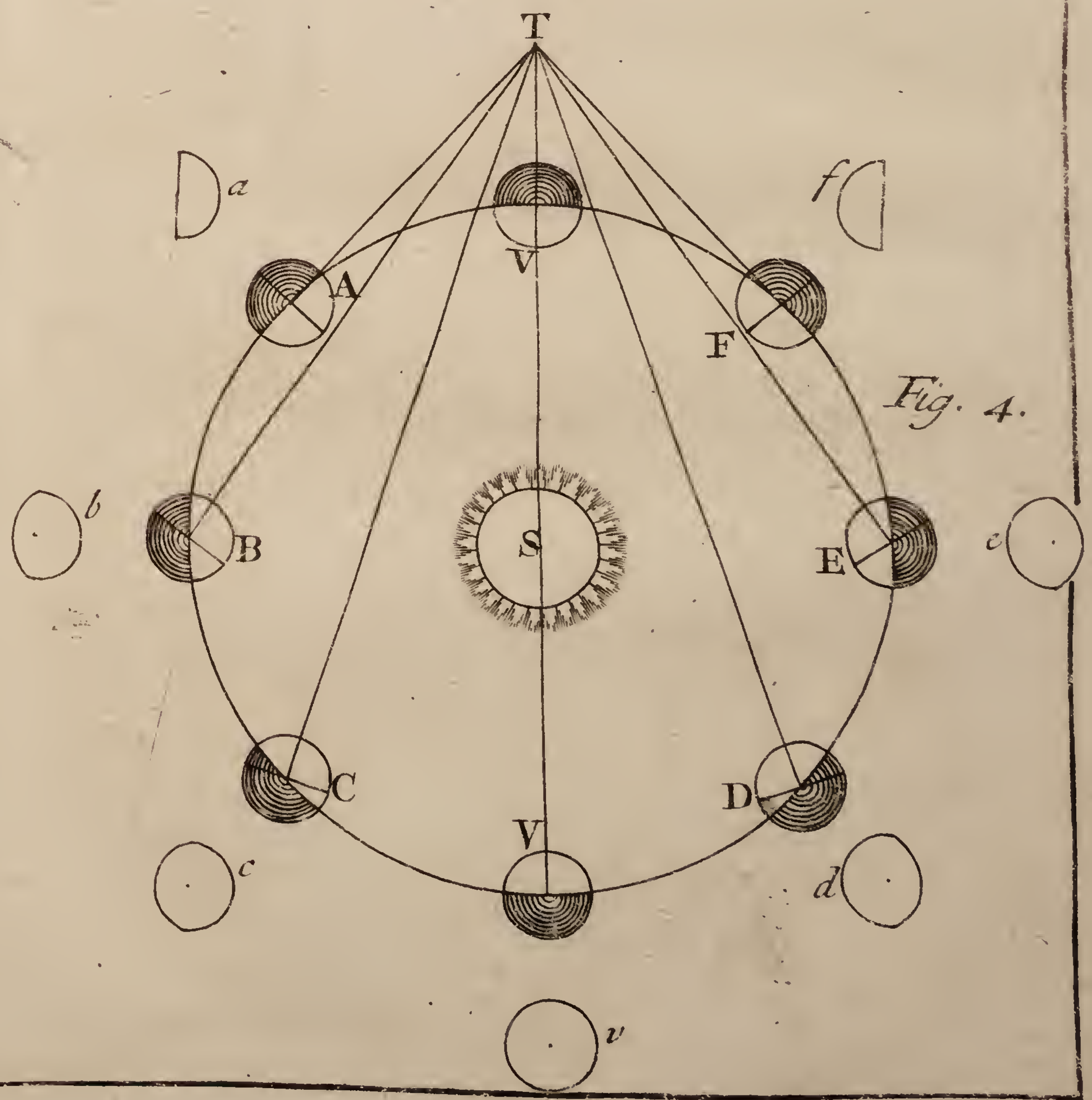


Fig. 3.



T
a
V
f
A
F
b
B
S
E
e
C
D
V
c
d
v

Fig. 4.

Vol. 2.

Jupiter and *Saturn* encompaſs the Orbit of the Earth at a great Diſtance; wherefore almoſt their whole Hemiſpheres which are enlighten'd by the Sun, are viſible from the Earth; and therefore theſe Planets *always appear round.* 1028

Becauſe *Mars* is leſs diſtant, it *appears a little gibbous, between the Conjunction and Oppoſition with the Sun.* 1029

CHAP. VI.

Concerning the Phænomena of the Satellites, from their Motion in their Orbits. Where we ſhall ſpeak of the Eclipſes of the Sun and Moon.

THE *Satellites of* Jupiter *and* Saturn *do always accompany their Primaries in their Motion, and never appear to recede from them beyond certain Limits on either Side,* which may be eaſily determin'd from their Diſtances from their Primaries; *and they are alternately carried* in *Antecedentia* and in *Conſequentia.* Sometimes all of them are on the ſame Side of the Primary Planet, and ſometimes the Primary is obſerv'd to be between them; *they are* all *always in the ſame Right Line,* 1031 *or very little diſtant from it.* All which Things may be deduc'd from this, That the Motion about the Primary Planets is perform'd in Planes that make ſmall Angles with one another, and with the Plane of the Ecliptic. 1030

All *the Satellites of* Saturn *or* Jupiter are not viſible at the ſame time; *ſometimes* they *are hid by their Primary,* and *often immers'd in its Shadow.* 1032

DEFINITION I.

Plate XXII. *Fig.* 2.] Such an Immerſion in the Shadow is call'd an *Eclipſe of the Satellite* 1033

Let S be the Sun, T *t* the Orbit of the Earth, I *Jupiter*, M *m* the Orbit of a Secondary of *Jupiter.* Whilſt the Secondary moves from M to *m*, it undergoes an Eclipſe; and not being enlighten'd by the Sun, becomes inviſible. If the Earth be at T, the Immerſion into the Shadow is eaſily obſerv'd; on the contrary, the Immerſion is more ſenſible if the Earth be plac'd at *t*.

1034 Amongſt the Bodies that accompany *Saturn*,
*963 we have ſaid that there is *a Ring*;* concerning which it is to be obſerv'd, *that an Obſerver upon the Earth never ſees it wider than it is repreſented in the 4th* Fig. *of Plate* XX; *and that ſometimes it is inviſible*; namely, when the Plane of the Ring, being continued, goes thro' the Earth; for the Thickneſs of the Ring is not ſenſible. The Ring alſo is inviſible, when its Plane continued paſſes between the Earth and the Sun; for then the enlighten'd Surface of the Ring is turn'd from the Earth; in each Caſe *Saturn* appears round, yet in the laſt Caſe, by reaſon of the Rays that are intercepted by the Ring, there appear a black Belt upon the Surface of the Planet, like that which is occaſion'd by the Shadow of the Ring.

The Phænomena of the Earth's Satellite, namely of the Moon, are very remarkable in reſpect to us, and therefore particularly to be explain'd.

1035 It is very often in Conjunction with the Sun,
and as often in Oppoſition to it, but not at every
Revolution of the Moon in its Orbit; for whilſt
the Moon, after one entire Revolution of 27
1036 Days and 7 Hours, returns again to the Place
amongſt the fix'd Stars, in which it was in Con-
*960 junction with the Sun, the Sun is gone from that
996 Place, and is about 27 Deg. diſtant from it:*
998 there-

therefore *the neighbouring Conjunctions are twenty nine Days and a half diſtant from one another.*

DEFINITION II.

The Lunar Periodical Month *is the Time of one Revolution of the Moon in its Orbit.* 1037

DEFINITION III.

The Moon's Synodical Month, or a Lunation, *is the Time that the Moon ſpends between the two next Conjunctions with the Sun.* 1038

The Moon is inviſible in its Conjunction with the Sun, becauſe the enlighten'd Hemiſphere is turn'd from the Earth. Let T *(Plate* XXII. *Fig.* 3.) be the Earth, N the Moon between the Sun and the Earth, the enlighten'd Hemiſphere will be *m l i*, which cannot be ſeen from the Earth. 1039

Whilſt the Moon is carried, in its Orbit, *from the Conjunction to the Oppoſition,* the enlighten'd Part, which is directed towards the Sun, *does continually become more and more viſible to the Inhabitants of the Earth*; and in the Points A, B, C, the Moon does ſucceſſively acquire the Figures *a*, *b*, *c*. 1040

At P, *in its Oppoſition with the Sun it appears round, then going thro'* D, E, F, *it decreaſes,* as it is repreſented at *d*, *e*, *f*. 1041

DEFINITION IV.

The Conjunction of the Moon with the Sun is called the New-Moon. 1042

After the Conjunction, the Moon is as it were renew'd.

DEFINITION V.

The Oppoſition of the Moon with the Sun is call'd the Full-Moon, *becauſe the whole Moon appears enlighten'd.* 1043

DEFINITION VI.

1044 *The Conjunction and Oppoſition of a Satellite with the Sun, are called by the common Name of* Syzygies.

1045 At A and F the dark Part of the Moon is a little enlighten'd by the Rays that are reflected from the Earth; and therefore it is ſeen by a Spectator to whom the Sun is not viſible, that is, in the firſt Caſe, after the ſetting of the Sun, and in the ſecond, before its Riſe.

DEFINITION VII.

1046 *When the Light of the Sun is intercepted by the Moon, ſo that in reſpect of any Obſerver upon the Earth the Sun is partly or wholly cover'd, the Sun is ſaid to undergo an* Eclipſe.

Properly ſpeaking, this is an Eclipſe of the Earth, on whoſe Surface the Shadow or *Penumbra* of the Moon falls.

DEFINITION VIII.

1047 An Eclipſe of the Moon *is the Obſcuration of the Moon by the Shadow of the Earth.*

1048 *The Eclipſe of the Sun is never obſerv'd, except at the Time of the New-Moon.*

1049 *The Moon is never eclipſed but at the Time of the Full-Moon.*

1050 Yet the Luminaries are not eclipſed at every one of the Syzygies, becauſe the Moon does not move in the Plane of the Ecliptic,* in which the Sun and Earth always are; wherefore, upon Account of the Moon's Latitude, its Shadow, at the New-Moon, often does not touch the Earth; and itſelf at the Full-Moon paſſes beſide the Shadow of the Earth. * 969

1051 But *when the Moon* has no Latitude, or but very little, that is, when it *is in the Node, or near it, at its Syzygies, an Eclipſe is obſerved*; in that

Plate

Caſe the Moon appears to be in the Ecliptic, or very near it; and this it is that has given the Name to that Line.

Plate XXIII. *Fig.* 1.] That what relates to
the Eclipſe of the Moon may appear the more
plainly, let O O be the Way of the Moon, RR
the Plane of the Ecliptic; the Center of the
Earth's Shadow is always in it;* N is the Node * 940,
of the Moon's Orbit. 939

If the Center of the Earth's Shadow be at A, the Moon that goes by at F will not be darken'd.

If the Moon be leſs diſtant from the Node at 1052
the Full-Moon, as at G, the Shadow of the
Earth is at B, and *the Moon is darken'd in part*;
this is called a Partial Eclipſe.

If, ſuppoſing the Shadow at D, the Moon be 1053
Full, *the Moon* will *be wholly darken'd* at I, it runs
into the Shadow at L, and goes out of it at H;
and *the Eclipſe is ſaid to be Total.*

The Eclipſe is ſaid to be Central, when the Center 1054
of the Moon goes thro' the Center of the Shadow,
which only happens in the very Node N.

We have hitherto ſpoken of the Shadow of the
Earth; becauſe when we mention the Earth, we
underſtand its Atmoſphere which is join'd to it,
of which we have ſpoken elſewhere:* *The Sha-* * 418
dow of the Atmoſphere is properly *conſidered in Lu-* 1055
nar Eclipſes; for the Shadow of the Earth itſelf
does not reach the Moon.

Plate XXIV. *Fig.* 1.] Let T be the Earth, the Atmoſphere about it F D G G D F. The Sun's Rays B D, B D, touching the Atmoſphere; theſe go ſtreight on, and terminate the Shadow of the Atmoſphere, out of which if the Moon be, it is immediately enlighten'd by the Sun's Rays, but it is not enlighten'd in the ſame manner all the while it is between B D and B D.

1056 *The Rays which enter the Atmoſphere obliquely* are
* 617 refracted ;* and as they come towards the Earth
they continually penetrate into a Medium which
* 424, is denſer and denſer,* and therefore are every
429 Moment inflected and *move in Curves.* So the
* 617 Rays E F, E F, penetrate the Atmoſphere in the
Curves F G, F G, that touch the Earth. All
the Light between E F, E F, is intercepted by
the Earth, and the Rays G A, G A, terminate
the Earth's Shadow.

The Light between E F and B D, being refracted by the Atmoſphere, is ſcatter'd between G A and B D continued, and beyond A, the Point of the Earth's Shadow, the Lights that come from all Parts are confounded, but are continually weaker and weaker the farther from
1057 the Earth : So that *the Shadow of the Atmoſphere is* not a perfect Shadow, but *a weak Light,* whereby the Moon is viſible in an Eclipſe.

1058 *The Shadow of the Atmoſphere* is Conical, becauſe the Sun's Diameter is greater than the Diameter of the Atmoſphere, which is ſcarce bigger than that of the Earth ; and this Cone *does not reach quite to Mars,* as appears from immediate Obſervations ; but the Shadow of the Diameter, in the Place where it is cut by the Moon's Orbit, is ſcarce one Fourth leſs than the Diameter of the Earth.

With the ſame Reaſoning that we have prov'd that the Moon comes into the Shadow of the Atmoſphere, when the Moon in its Full is in the Node or near it ; it is alſo proved, that the Moon's Shadow falls upon the Earth *at the New-Moon, when the Moon is in the Node or near the*
1059 *Node* ; therefore in that Caſe *the Sun undergoes an Eclipſe* ; concerning which, ſeveral Things are to be obſerv'd.

Plate XXII. *Fig.* 4.] Let S be the Sun, **T** the Moon; let the Shadow of it fall upon any Plane GH. This Shadow is encompaſs'd with a Penumbra, for beyond L and E that Plane is enlighten'd by one entire Hemiſphere of the Sun; as you go from L to H, and from E to G, the Light is continually diminiſhed, and near G and H the Rays come to the Plane only from a ſmall Part of the Sun's Surface.

DEFINITION IX.

This diminiſh'd Light, which encompaſſes the Shadow G H *every Way, is call'd* the Penumbra. 1060

In the Eclipſe of the Moon, the Shadow of the Earth is encompaſs'd with *the like Penumbra,* but this is only ſenſible near the Shadow, and therefore *has but a ſmall Breadth*; *but* if *an Obſerver* be plac'd upon a Plane upon which the Shadow falls, he *may obſerve the whole Penumbra*; as is the Caſe *in the Eclipſe of the Sun.* An Obſerver I or F can only ſee the Semidiameter of the Sun, the reſt of the Diameter is hid by the Moon; and going from L towards H, the Sun is continually more and more hid by the Moon, till it becomes wholly inviſible in the Shadow itſelf. 1061 1062

Hence it follows, that *there is a Solar Eclipſe, tho' the Shadow of the Moon does not touch the Earth, provided the Penumbra comes to its Surface.* And alſo, *that the Eclipſe is not obſerved in all the Places in which the Sun is viſible*; *and that it is different,* according as the Shadow or a different Part of the Penumbra goes thro' the Place, *in the Places in which it is obſerv'd.* 1063 1064 1065

But the Eclipſe of the Moon is every where the ſame, where the Moon is viſible, during the Eclipſe. 1066

But when the Shadow itſelf of the Moon falls upon the Earth, the Sun's Eclipſe is ſaid to be Total; *if only the Penumbra reaches the Earth, it is ſaid to be* 1067

Partial; and this is what happens when we conſider an Eclipſe in general.

1068 But as to particular Places, *it is ſaid to be Total in thoſe Places where the Shadow paſſes*; *Central, in thoſe* where the Center of the Shadow paſſes, that is, *where the Center of the Moon covers the Sun's Center*; and laſtly, *Partial, where the Penumbra only goes by*; and this is drawn in *Fig.* 6.

1069 *Plate* XXII. *Fig.* 4.] *The wider the Shadow* **H** *is, the more Places is the Eclipſe of the Sun Total in, and the longer is the Sun wholly obſcured.* But the Breadth of the Shadow is different according to the different Diſtance of the Moon from the Earth, and of the Earth from the Sun.

1070 *If there be an Eclipſe of the Moon, ſuppoſing the Earth in the Perihelion,* and *the Moon in the Apogæum,* that is, at the greateſt Diſtance from the Earth, the Shadow of the Moon does not reach the Earth, and *the Moon does not cover the whole Sun*; *ſuch an one is* call'd *an Annular Eclipſe*, and is repreſented in *Fig.* 5.

CHAP. VII.

Of the Phænomena ariſing from the Motion of the Sun, the Planets, and the Moon, about their Axes.

1071 THE *Sun's Motion about its Axis is ſenſible, by obſerving the Spots,* which are obſerv'd very often upon the Sun's Surface; theſe Spots ſeem to change their Figure and Situation every Day, and ſometimes to move ſwifter, ſometimes ſlower; all which Things may be eaſily deduc'd from the Motion of a Spherical Surface; and the Sun, which, if it was not mov'd by ſuch a Motion, would only once in a Year ſucceſſively turn its whole Surface to the Earth, now ſhews it to the Inhabitants of the Earth in leſs than the Space of one Month.

1072 Such like Phænomena ariſe from *the Rotation of Jupiter, Mars, and Venus, about their Axes,* which Motions *become ſenſible, by obſerving the Spots in the Surfaces of the Planets.*

Whilſt the Earth is mov'd round its Axis, the Obſerver, who is carried round, imagines himſelf to be at Reſt, and all the heavenly Bodies to be in Motion.

DEFINITION I.

1073 *The Points, in which the Axis of the Earth being continu'd both Ways, touches the Sphere of the fix'd Stars, are call'd the* Poles of the World.

DEFINITION II.

1074 *The apparent Motion, ariſing from the Motion of the Earth about its Axis, is call'd* the Diurnal Motion.

DEFINITION III.

1075 *A Plane is conceiv'd to paſs thro' the Center of the Earth, perpendicular to its Axis, and continu'd every Way, and the Circle in which it cuts the Sphere of the fix'd Stars, is call'd* the Cœleſtial Æquator.

1076 *In the Motion of the Earth round the Sun,* the Æquator is mov'd; but ſince the Plane of this Circle is carried by a parallel Motion, *the Cœleſtial Æquator is not mov'd.** *994

DEFINITION IV.

1077 *Circles whoſe Planes go thro' the Axis of the Earth, are call'd* Meridians.

1078 *They all paſs thro' the Poles of the World, and are perpendicular to the Æquator.*

DEFINITION V.

1079 *The Arc of any Meridian which intercepted between the Æquator and a Star, is call'd* the Declination of that Star.

Plate XXIII. *Fig.* 2.] Let an Obſerver be upon the Earth T, who directs his Sight along T A; after a little Time, when the Line T A ſhall be caried by the Motion of the Earth to T *a*, if the Spectator directs his Sight thro' the ſame Line, the Body A will appear to have been carried thro' the Arc *a* A; but when the Line has return'd to its former Situation T A, the Body will ſeem to have perform'd one whole Revolution. But if he directs his Sight along the Axis of the Earth produc'd, becauſe that's at Reſt, the Body which is ſeen in the Axis will appear not to
1080 have mov'd; therefore *in the Poles of the World the*
*1073 *diurnal Motion is not obſerv'd.** But that Bodies which are near the Poles are mov'd round them is plain; and that the Body by its diurnal Motion deſcribes ſo much a greater Circle round the immoveable Pole, as it is farther diſtant
1081 from it. Therefore *the whole Sphere of the fix'd Stars ſeems to revolve about the Axis of the Earth continu'd,* in Antecedentia, *in that Time in which the Earth really turns about its Axis.* Therefore the diurnal Motion is common to all the Cœleſtial Bodies, except ſo far as it is diſturb'd by the Motions above-mention'd.

The Æquator is equally diſtant from both Poles, and divides the Heavens into two Hemiſpheres, whoſe middle Points are the Poles, which therefore are equally diſtant from the ſe-
1082 veral Points of the Æquator; therefore *the heavenly Bodies which are in the Æquator, by their diurnal Motion ſeem to deſcribe the Æquator itſelf,* the greateſt Circle of all that can be deſcrib'd

by the diurnal Motion; *the other Bodies deſcribe* 1083
Circles parallel to the Æquator.

The Axis of the Earth is inclin'd to the Plane of the Ecliptic in an Angle of 66 Deg. 31 Min.* *960
The Poles of the World therefore *are diſtant from* 1084
the Poles of the Ecliptic 23 Deg. 29 Min. *and the Plane of the Æquator makes an Angle with the Plane of the Ecliptic of* 23 Deg. 29 Min. Both Planes paſs thro' the Center of the Earth; but ſince this may be look'd upon as the Center of the fix'd Stars,* it follows, that *the Æquator and the* 1385
Ecliptic Line are great Circles, which are inclin'd to *988
each other, and *cut one another in two oppoſite Points,* 990
in the Beginning of Aries, *and the Beginning of* Libra; which Points, in the way of the Sun, are determin'd by theſe Interſections.* *1001

When the Sun is in thoſe Points, it ſeems to deſcribe 1086
the Æquator by its diurnal Motion; when it is car-* 1087
ried about *in the Ecliptic* by its Apparent Motion, *1082
it continually recedes more and more from the Æquator, and its Declination is encreas'd, *and* it *deſcribes leſs Circles every Day;* till it comes to its* *1083
greateſt Diſtance from the Æquator, which is 23 1088
Deg. 29 Min.* *then it comes back to the Æquator* *1084
again, and goes beyond it alſo 23 Deg. 29 Min. *advancing towards the oppoſite Pole.*

DEFINITION VI.

Thoſe Circles, deſcrib'd by the Sun in its diurnal 1089
Motion, which are moſt diſtant from the Æquator, that is, 23 Deg. 29 Min. *are call'd* the Tropics.

One touches the Ecliptic Line in the firſt Degree of *Cancer*, and is call'd the Tropic of *Cancer*; the other is call'd the Tropic of *Capricorn*, and paſſes thro' the firſt Point of the Sign *Capricorn*, and there touches the Ecliptic Line.

DEFINITION VII.

1090 *The Pole of the World which is next to the Tropic of* Cancer, *is call'd the* Arctic Pole, *and alſo the* North Pole; *the oppoſite is call'd* the Antarctic, *and alſo* the South Pole.

DEFINITION VIII.

1091 *The Circles* that are deſcrib'd in the diurnal Motion by the Poles of the Ecliptic, that is, by the Points *which are diſtant from the Poles of the World* 23 Deg. 29 Min. *are call'd* the Polar Circles.

The Arctic Polar Circle is that which ſurrounds the Arctic Pole; the other oppoſite one borrows its Name from the Antarctic Pole.

There remains to be explain'd *the Moon's Mo-*
1092 *tion about its Axis, whoſe Effect is, that the ſame Face of the Moon is always turn'd towards the Earth.*

Plate XXII. *Fig.* 3.] Let the Moon be at N, the Face which is turn'd to the Earth is *m n i*; if the Moon did not turn about its Axis, and all its Points were carried thro' parallel Lines, the Line *m i* would coincide with the Line *l n* in the Situation of the Moon at B, and the aforeſaid Hemiſphere *m n i* would be at *l m n*; but becauſe whilſt the Moon deſcribes a fourth Part of its Orbit, it performs likewiſe $\frac{1}{4}$ of its Revolution round its Axis, the Face which would be at *l m n*, is now at *m n i*, that is, again turn'd to the Earth. After the ſame Manner it is prov'd, that this ſame Face *m n i*, when the Moon is at P, is ſeen by an Obſerver on the Earth, and that it is turn'd towards the Earth at E; as alſo in all other Points of the Moon's Orbit.

1093 *The Axis of the Moon* is not perpendicular *to the Plane of its Orbit*, but *a little inclin'd* to it: The Axis keeps its Paralleliſm in its Motion round the Earth, as has been ſaid of the Primary

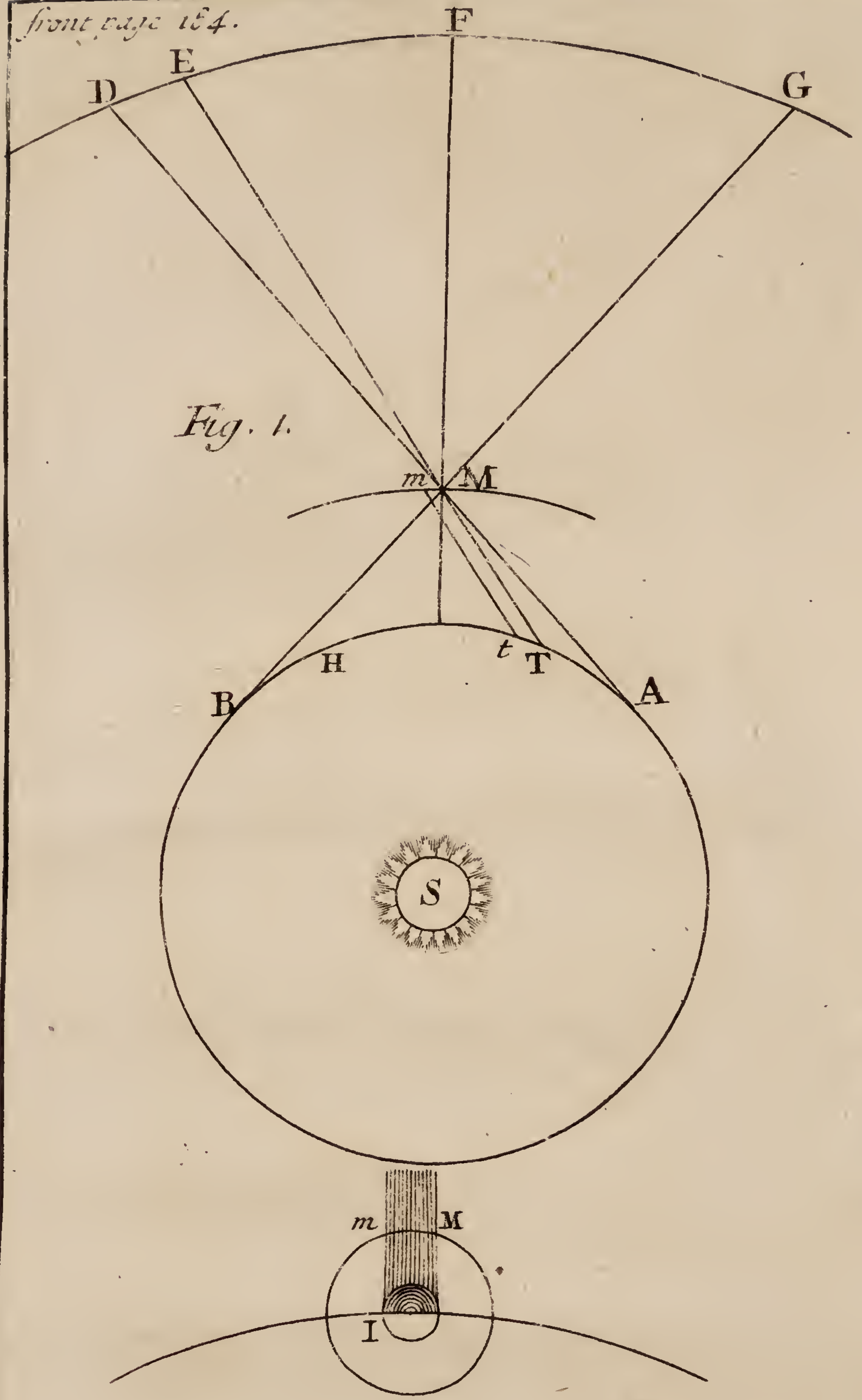

D
E
F
G
m
M
B
H
t
T
A
S
m
M
I

Fig. 1.

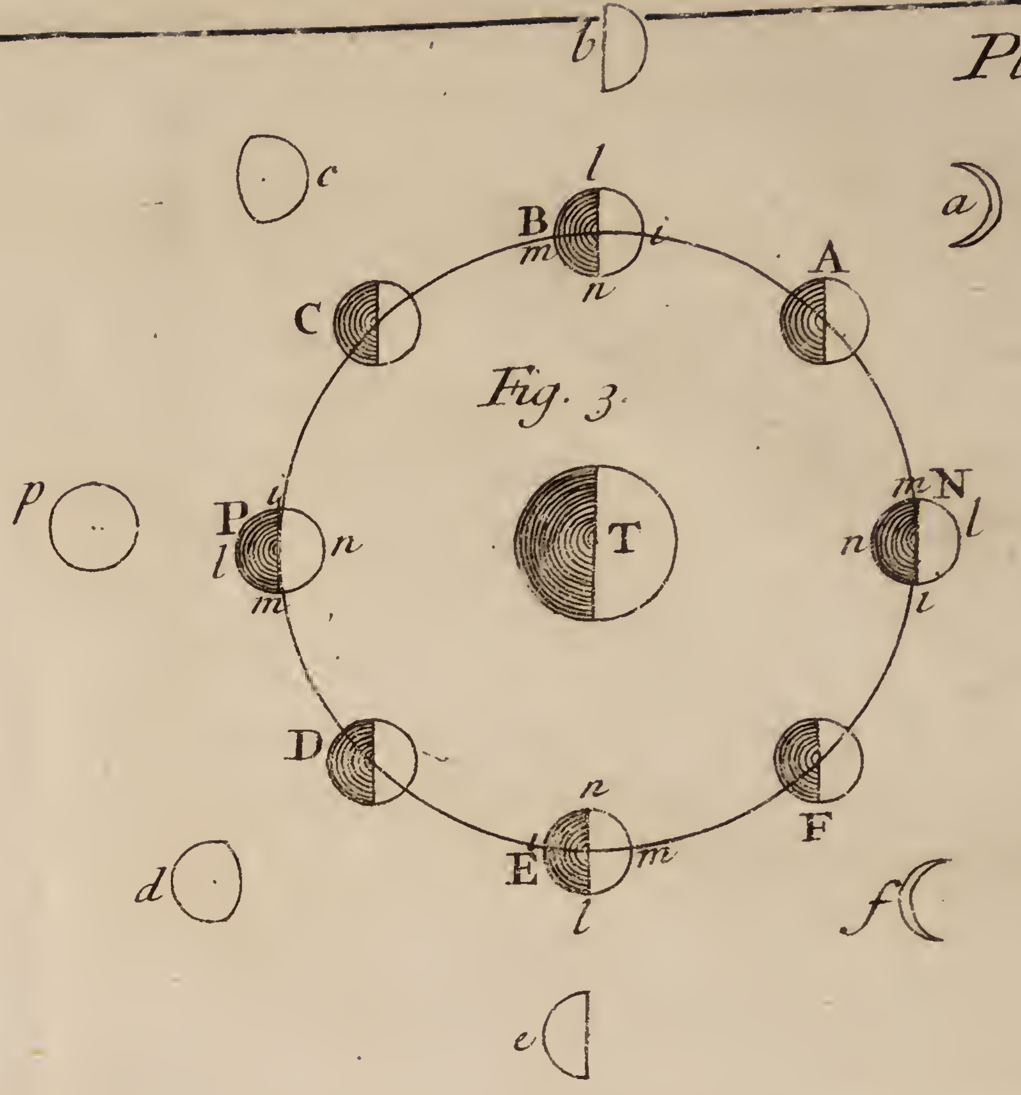

b
c
l
B
m
i
n
A
a
C
p
P
i
l
m
n
T
m
N
n
l
i
D
d
n
E
i
m
l
F
f
e

Fig. 3.

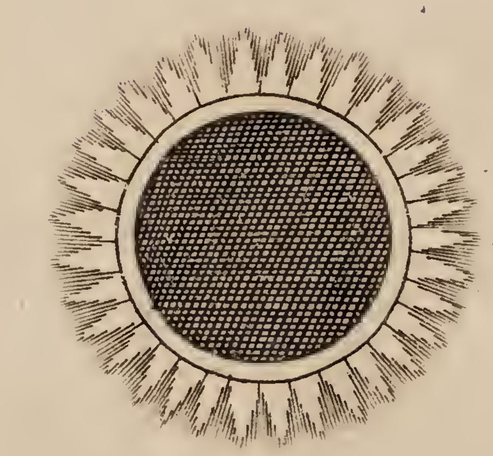


Fig. 5.

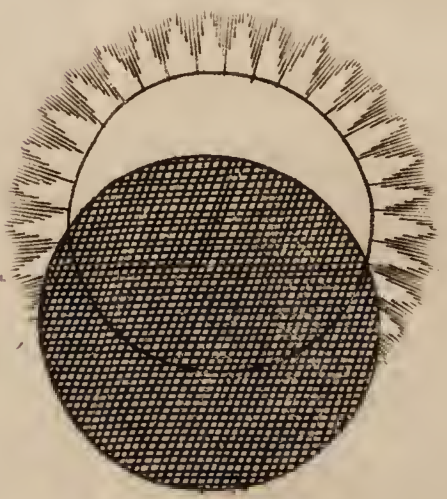
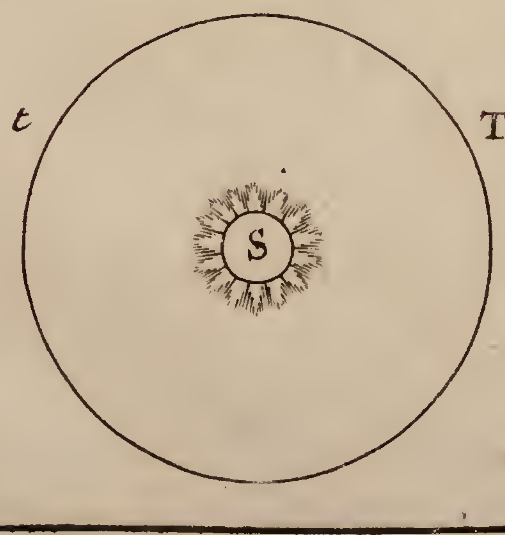


Fig. 6.

Fig. 2.



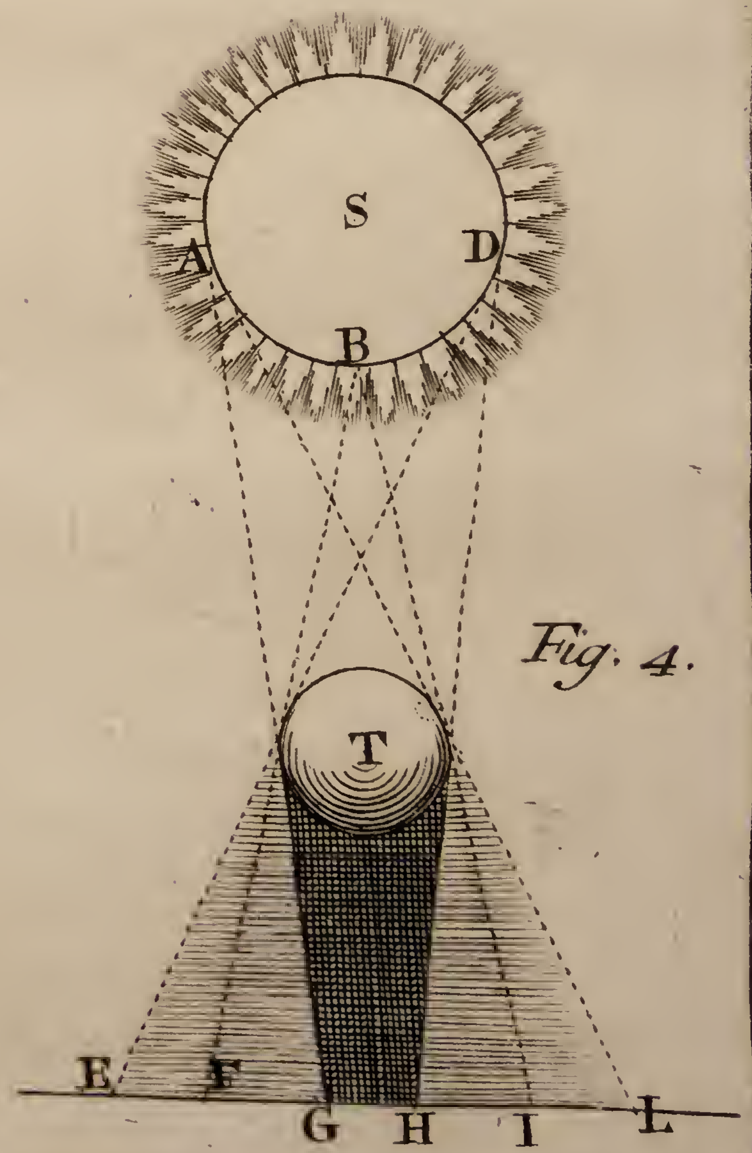

S
A
D
B
T
E
F
G
H
I
L

Fig. 4.

mary Planets ;* therefore it changes its Situation * 952
in reſpect of an Obſerver on the Earth, to whom ſometimes one, ſometimes the other Pole of the Moon is viſible, whence *it ſeems to be agitated by a* Sort of *libratory Motion.* There is another libratory Motion obſerv'd in the Moon; the Motion about the Axis is equable, and it is carried in its Orbit with an unequal Celerity ;* therefore when the Moon is at its *Perigæum*, that is, at its leaſt Diſtance from the Earth where it is mov'd the ſwifteſt in its Orbit,* that Part of its Surface which, on Account of its Motion in the Orbit, wou'd be turn'd towards the Earth, is not wholly turn'd from it on Account of its Motion round its Axis: Therefore ſome of that Part of the Surface of the Moon which before was not viſible, is ſeen at the Side; which, when the Moon is at its *Apogæum*, is again inviſible. 1094 * 966 * 996

CHAP. VIII.

Of the Phænomena which relate to the Surface of the Earth, and its particular Parts.

WE have explain'd the Cæleſtial Phænomena hitherto examin'd, by conſidering the Spectator as carried about by thoſe Motions wherewith the Earth is really mov'd. Now we ſhall conſider him as plac'd upon the Surface of the Earth, and carried from one Place to another upon it.

1095 The firſt Phænomenon to be here obſerv'd is, that *by Reaſon of the Interpoſition of the Earth, one half of the Heavens is inviſible to the Obſerver who is plac'd upon the Surface of the Earth.*

DEFINITION I.

1096 *That Circle in the Heavens which ſeparates the viſible from the inviſible Part*, when the Rays are not intercepted by the Inequalities of the Earth's Surface, *is call'd the* Horizon.

When the Height to which the Spectator can be rais'd above the Surface of the Earth, is very ſmall, compar'd with the Semidiameter of the Earth; the Eye of the Spectator may be look'd upon as plac'd in the Surface itſelf.

Plate XXIII. *Fig.* 4.] Let the Earth be **T**, and the Obſerver at S, and P E *p e* the Sphere of the fix'd Stars; if you conceive a Plane at H H to touch the Earth and go thro' S, it will be the Plane of the Horizon, whoſe Section with the Sphere of the fix'd Stars is the Horizon. A Plane as *h h*, is conceiv'd to go thro' the Center of the Earth, parallel to H H; the Diſtance *h* H is inſenſible, by reaſon of the immenſe Diſtance of the fix'd Stars; therefore the Section of that Plane, with the Sphere above-mention'd, may be taken for the Horizon.* * 994

DEFINITION II.

1097 *The Aſcent of the* Stars *above the Horizon, is call'd their* Riſe.

DEFINITION III.

1098 *The Deſcent below the Horizon, is call'd the* Setting *of the Stars.*

DEFINITION IV.

1099 *If we conceive a Line drawn thro' the Obſerver and the Center of the Earth,* which muſt neceſſarily be perpendicular to the Horizon, *it will reach the Point Z among the fix'd Stars, which is call'd the* Zenith.

DEFINITION V.

1100 *The Point* N *oppoſite to it is call'd the* Nadir.

DEFINITION VI.

1101 *The Section which a Plane of a Meridian, that goes thro' the Obſerver, makes with the Horizon, is call'd the* Meridian Line; and is directed from North to South.

DEFINITION VII.

The Eaſtern Part of the Heavens *is that, from* 1102
which we ſee the Bodies riſe above the Horizon ; and the Eaſt Point *is that in which a Line directed Eaſtwards perpendicular to the Meridian Line, and going thro' the Obſerver cuts the Sphere of the fix'd Stars.*

DEFINITION VIII.

The Point oppoſite to this is call'd the Weſt Point ; 1103
and the Weſtern Part of the Heavens *is oppoſite to the Eaſtern Part.*

DEFINITION IX.

The Amplitude *is an Arc of the Horizon, which* 1104
is contain'd between the Eaſt or Weſt Point, and the Point in which the Star riſes or ſets. The firſt is call'd the Riſing, and the other the Setting Amplitude : And each is either Northern or Southern Amplitude.

DEFINITION X.

The Height or Altitude of a Star above the 1105
Horizon, *is the Arc of a Circle perpendicular to the Horizon, in whoſe Center the Spectator is, terminated by the Horizon and the Star.*

DEFINITION XI.

The Difference of the Height of a Star, according 1106
to the different Poſition of the Obſerver, as he is ſuppos'd in the Center, or on the Surface of the Earth, is call'd the Parallax of the Star.

There is only the Parallax of the Moon which can 1107
be determin'd by Obſervations : The Diſtance of the reſt of the Bodies in the Planetary Syſtem is too great to be compar'd with the Semidiameter of the Earth ; and the Parallax depends upon the Ratio which the Semidiameter of the Earth has to

to the Diſtance of a Planet; therefore even *the*
1108 *Parallax of* Mars *in Oppoſition with the Sun, is too*
ſmall for the niceſt Obſervations.

1109 Where there is a *Parallax,* it *diminiſhes as a Body*
aſcends above the Horizon, and vaniſhes in the Zenith.

The apparent Height of the Stars is alſo
changed upon another Account, which equally
1110 affects all the heavenly Bodies. The Rays are
1111 inflected *by the Refraction of the Atmoſphere,** and
*1056 *the Stars appear higher than they are;** *yet the higher*
*624 *they are, the leſs is that Inflection;** becauſe the
*639 Rays fall leſs obliquely on the Surface of the
1112 Atmoſphere. *In the* Zenith *there is no Refraction;*
even at the Diſtance of twenty or thirty Degrees from
the Zenith *it is not ſenſible.*

1113 Since *the Stars* are rais'd *by this Refraction,* they
are viſible before they come to the Horizon.

Plate XXIV. *Fig.* 2.] All theſe Things relate to the Surface of the Earth in general, now we muſt examine the ſeveral Parts of it; theſe are determin'd, by referring to the Earth the ſeveral Circles which we have before conſider'd
1114 in the Heavens; ſo *on the Earth we conſider the Æquator, the Meridians, the Tropics, and Polar Circles;* and theſe Circles divide the Surface of the Earth in the ſame manner as the Sphere of the fix'd Stars is divided by the Circles in the Heavens: And therefore the Circles in the Heavens, and thoſe upon the Earth do ſo mutually correſpond with each other; that a Line being drawn from the Center of the Earth to a Circle in the Heavens, it will go thro' the ſame Circle in the Earth. If the Poles are P, *p*, the Æquator will be E *e*, the Tropics T T, *t t*, and the Polar Circles A A *a a*.

DEFINITION XII.

1115 *The Meridian which goes thro' a Place, is call'd the* Meridian of the Place.

The

1116 *The Plane of it is perpendicular to the Horizon;* becauſe it goes thro' the Center of the Earth, and the Obſerver.

1117 *A Meridian Line drawn in any Place, is part of the Meridian of the Place.** *1101

DEFINITION XIII.

1118 The Latitude of a Place *is its Diſtance from the Æquator;* that is, the Arc intercepted between that Place and the Æquator.

DEFINITION XIV.

1119 *Circles parallel to the Æquator, are call'd* Circles of Latitude.

By determining the Latitude of the Place, we determine the Circle of Latitude, which goes thro' the Place; now to determine the Situation of ſeveral Places in reſpect of each other, we muſt determine Places upon the ſeveral Circles, which is done, by ſuppoſing a Meridian to paſs thro' any remarkable Place, which by its Section, determines a Point upon each Circle of Latitude, from which the Diſtances of Places are meaſur'd.

DEFINITION XV.

1120 *The Meridian above-mention'd, taken at Pleaſure, is call'd the* Firſt Meridian.

DEFINITION XVI.

1121 *The Diſtance of a Place from the firſt Meridian, meaſur'd on a Circle of Latitude that goes thro' a Place, is call'd the* Longitude of the Place.

1122 *Aſtronomers refer every Thing to the Meridian of the Place, in which they make their Obſervations.*

In explaining the Phænomena which relate to the ſeveral Parts of the Surface of the Earth, we ſhall conſider the Obſerver going from the Pole to the Æquator; and firſt only take Notice of the diurnal Motion.

1123 *Plate* XXIII. *Fig.* 3.] When the Spectator is at S, in the very Pole of the Earth T, the cæleſtial Æquator E *e*, coincides with the Horizon, and the Pole of the World P is in the *Zenith*; in that Caſe, becauſe the Circles which are parallel to the Horizon are alſo parallel to the Æquator; all the heavenly Bodies appear to be carried by a Motion parallel to the Horizon,* in *1083 Circles which are repreſented by the Lines A *a*, B *b*. *The heavenly Bodies in the Hemiſphere* E P *e never ſet, and the others are never viſible. The Horizon in this Situation is ſaid to be parallel, or this Situation is call'd a Parallel Sphere.* 1124

1125 *Plate* XXIII. *Fig.* 4.] *If an Obſerver* upon the Earth T *recedes from the Pole,* and is at S, *the Horizon is ſaid to be oblique, or the Sphere is oblique*; then the Axis P *p* is inclin'd to the Horizon *h h*, ſo much the more as the Obſerver is farther from the Pole.

DEFINITION XVII.

1126 *The Angle which the Axis of the Earth makes with the Horizon, is call'd the* Height of the Pole.* *1105

1127 This *Height of the Pole is equal to the Latitude.* The Height of the Pole is the Angle P T *h*, whoſe Meaſure is the Arc P *h*; the Latitude is meaſur'd by an Arc, which upon the Earth correſponds to the Arc Z E in the Heavens:* But *1118 it is equal to the Arc P *h*; for the Complement of each of them to a Quarter of a Circle, is the Arc Z P.

1128 *In this Poſition of the Obſerver,* becauſe the Æquator is inclin'd to the Horizon, *all the heavenly Bodies are carried by the diurnal Motion in Circles inclin'd to the Horizon,* repreſented by the Lines A *a*, B *b*.

Some of the heavenly Bodies riſe and ſet at every 1129
Revolution of the Earth; namely, thoſe which are
between the Parallels to the Æquator B *h*, and
h i; becauſe all the Parallels between thoſe Two
are cut by the Horizon.

The Planes of the Æquator and the Horizon
go thro' the Center of the Earth; therefore theſe
Circles cut one another mutually into two equal
Parts, and half of the Æquator is above the
Horizon; therefore *the heavenly Bodies which are* 1130
in the Æquator are above the Horizon during half a
Revolution of the Earth about its Axis;* and on *1082
Account of the Equability of the Motion about
the Axis, *are inviſible during an equal Time.*

Theſe alſo riſe due Eaſt, and ſet due Weſt (that 1131
is, in the very Points of the Eaſt and Weſt;) for
the Section of the Planes of the Æquator and
the Horizon, is perpendicular to a Plane per-
pendicular to both theſe Planes; and this laſt
Plane is the Plane of the Meridian of the Place.* *1078
Wherefore the above-mention'd Section is per- 1116
pendicular to the Meridian Line,* and conſe- *1117
quently goes thro' the Eaſt and Weſt Points.* *1102
1103

Bodies between the Æquator and a Parallel B *h*,
which touches the Horizon, as in the Circle A *a*, *con-* 1132
tinue longer above than below the Horizon; and this
Difference is ſo much the greater, the more the Circle 1133
A *a*, *approaches that Pole, which is above the Horizon.*
On the contrary, *as the Body goes towards the*
oppoſite Pole, its Time of continuance above the Hori-
zon is the longer.

This Inequality of the Time that a Body is above 1134
and below the Horizon encreaſes as the Height of the
Pole does, becauſe of the Diminution of the An-
gle made with the Horizon by the Æquator and
its Parallels.

Bodies whoſe Diſtance from the Pole is equal to the 1135
Height of it, never ſet, for ſuch is the Diſtance
of

of the Circle B *h*, which touches the Horizon, but has no Part of it below the Horizon.

Bodies leſs diſtant from the Pole, do not ſo much as come down to the Horizon.

1136 It appears by the ſame Reaſoning, that *Bodies whoſe Diſtance from the oppoſite Pole does not exceed the Height of the Pole*, never riſe above the Horizon, and *are always inviſible.*

1137 Bodies whoſe Diſtance E Z from the Æquator is equal to the Height of the Pole, go thro' the Zenith Z, for E Z is equal to the Latitude of the Place to which the Height of the Pole is
1126 equal.

1138 *Plate* XXIII. *Fig.* 5.] *When a Spectator* S has receded as far as he can from the Pole, he *comes to the Æquator*, whoſe Points are equally diſtant
1075 from each Pole; then the Axis P*p* is in the Ho-
1114 rizon, with which the Æquator makes a right
1075 Angle, for which Reaſon the *Horizon is ſaid to*
1114 *be Right*; or this is call'd a *Right Sphere.*

The Horizon cuts into two equal Parts all the Circles that are parallel to the Æquator, which are repreſented by the Lines A *a*, B *b*, therefore
1139 *all the heavenly Bodies, at every Revolution of the Earth, riſe, and ſet, and are viſible and inviſible during equal Times.*

1140 *The Æquator* itſelf *goes thro' the Zenith, and therefore all the Bodies that are in it paſs thro' it alſo.*

If what we have explain'd concerning the Diurnal Motion be applied to the Bodies, of whoſe other apparent Motions we have ſpoken before, the Phænomena will be eaſily determin'd from the Motions join'd together; thoſe that relate to the Sun are more remarkable than the reſt, and therefore more particularly to be explain'd.

DEFINITION XVIII.

We call a Natural Day the Time elapſed between 1141
the Receſs of the Sun from the Meridian a Place of,
and its next Return to the ſame Meridian.

This Day differs from the Time of the Revolution 1142
of the Earth about its Axis, which Times would
be equal if the Sun appear'd immoveable amongſt
the fix'd Stars; but whilſt by the Diurnal
Motion, in the Time of one Revolution of
the Earth about its Axis, the Sun is carried round
from Eaſt to Weſt, that is, *in Antecedentia*,* it is *1080
carried by a contrary Motion in the Ecliptic,* *996
whereby it comes later to the Meridian.

But as the Sun does not every Day go thro'
an equal Space in the Ecliptick,* all the *Natural* *997
Days do not equally exceed the Revolution of 1143
the Earth about its Axis; therefore theſe Days
are *unequal to one another*.

Natural Days are unequal alſo upon another
Account, namely, by Reaſon of the Inclination
of the Ecliptic in Reſpect to the Æquator;
whence it follows, that the Annual Courſe of
the Sun is unequally inclin'd to the Æquator in
different Points; and tho' the Sun ſhould equally
go forward every Day in the Ecliptic, the natural
Days would not equally exceed the Time of
the Revolution about the Axis; for if the Motion
of the Sun be reſolv'd into two Motions,* *192
of which the one is parallel to the Æquator,
and the other perpendicular to it, the firſt is
only to be conſider'd in determining the Exceſs
above-mention'd, and that it is unequal, is plain
from the different Inclination above-mention'd.

Theſe two Cauſes of Inequality often concur,
and often act contrarywiſe.

Every Natural Day is divided into twenty-four 1144
equal Parts, which are call'd Hours. Each Hour is

divided into ſixty Minutes; and each Minute into
ſixty ſecond Minutes or Seconds; and ſo on. That
1143 *theſe Parts of Time vary in different Days,* appears
plainly from what has been ſaid; they are by
Aſtronomers reduc'd to Equality, by conſidering
the Number of Hours in the whole Revolution
of the Sun in the Ecliptic, and dividing the
whole Time into as many equal Parts as there are
Hours, twenty-four of which are taken for one
1145 Day. *The Time, whoſe Parts are* by this Method
reduc'd to Equality, is call'd the Mean Time, and
that Reduction is call'd the Æquation of Time.

1146 *We always make uſe of the Days and Hours of the Mean Time in determining the Periods of the heavenly Motions.*

DEFINITION XIX.

1147 The Artificial Day *is the Time that the Sun ſtays above the Horizon.*

We always ſpeak of it when we mention Day
1148 in Oppoſition to Night. *In determining the Length*
of Artificial Days, we ſhall not attend to the Æquation of Time.

1149 *The* Crepuſculum *always comes before the Sun's*
1150 *Riſe, and follows its Setting; this is that dim Light*
which we commonly call Morning and Evening Twilight.

1151 *The Twilight is produc'd by the Atmoſphere, which is enlighten'd by the Sun's Rays, and whoſe Particles reflect the Light* every Way; from whence ſome Rays come *to us, tho' the Sun be depreſs'd eighteen Degrees below the Horizon.*

1152 *In the parallel Sphere,* that is, to all thoſe that
1138 dwell under the Æquator, *the Days and Nights*
*1139 *are equal to one another all the Year round,** and are
1144 of twelve Hours.

1153 *In the oblique Sphere the Days are longer or ſhorter, according to the different Diſtance of the Sun from the* *front page 194.*

Plate 23.

Fig. 1

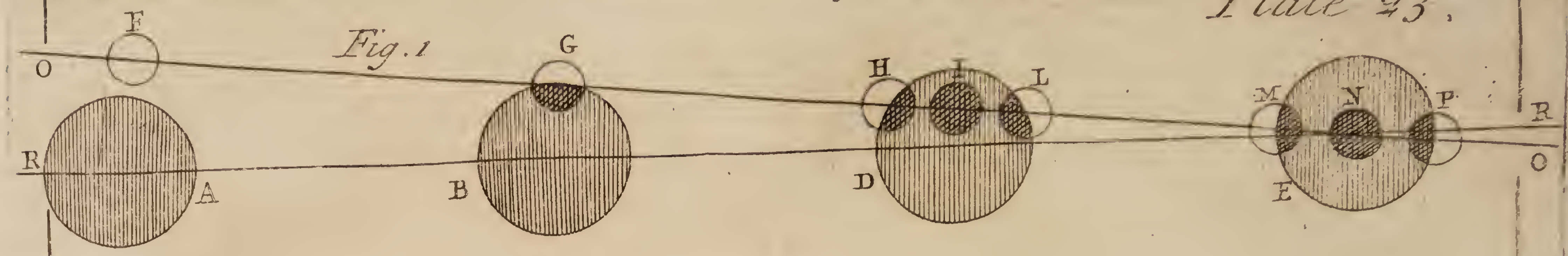

O
F
G
H
I
L
M
N
P
R
R
A
B
D
E
O

Fig. 2

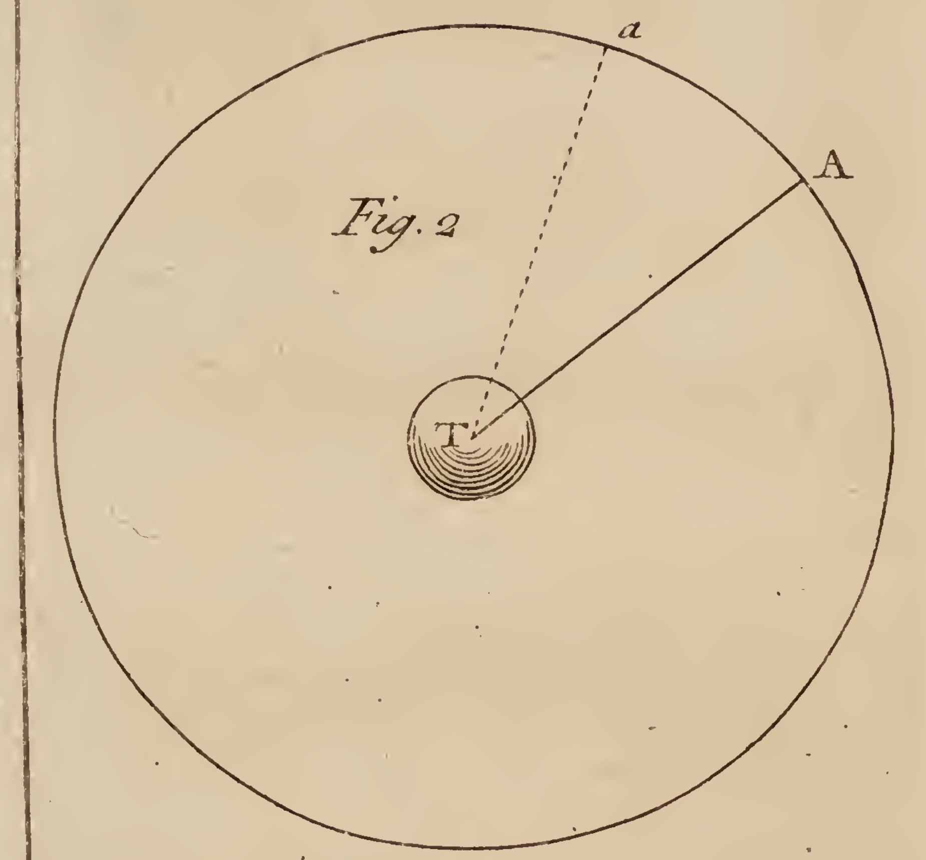


Fig. 3

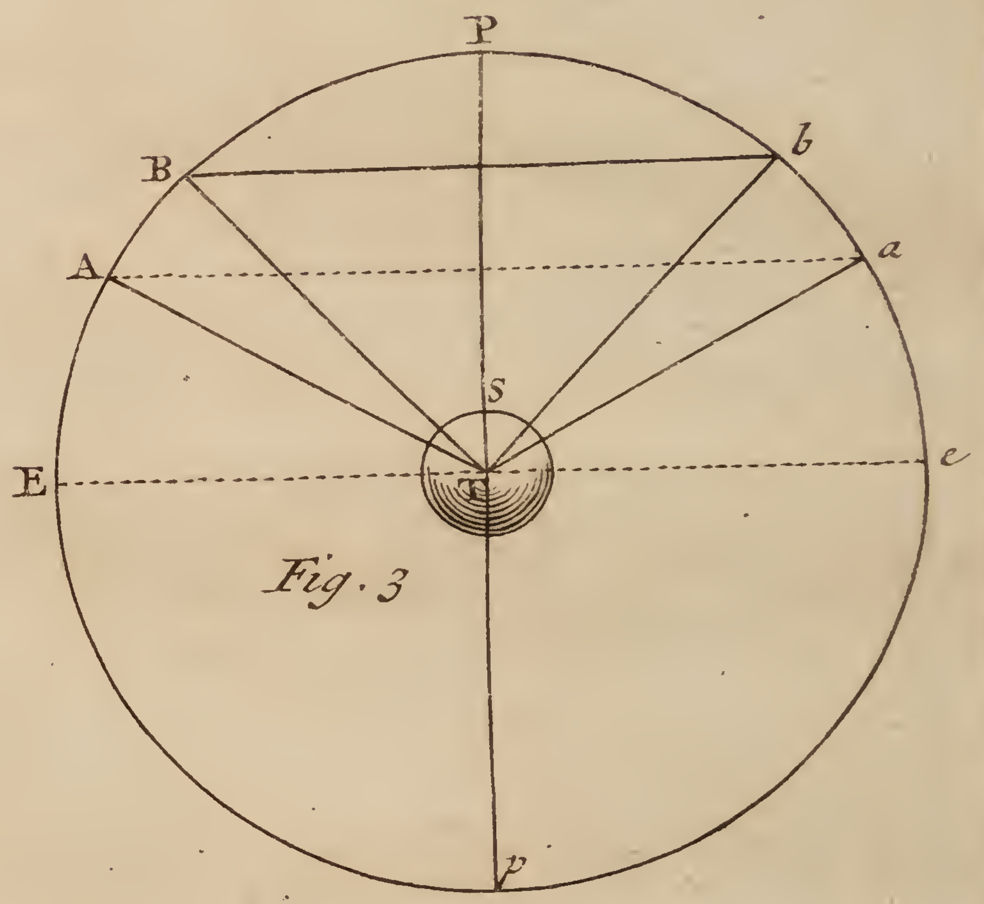

P
B
b
A
a
S
E
T
e
p

Fig. 4

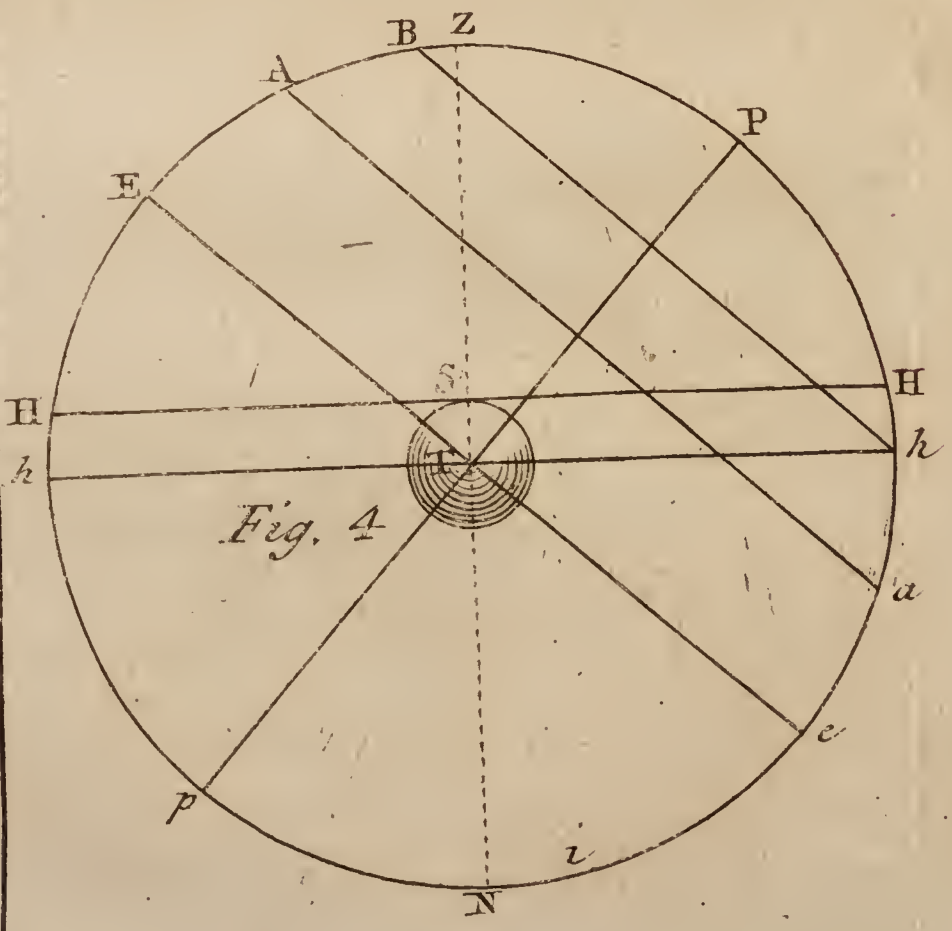
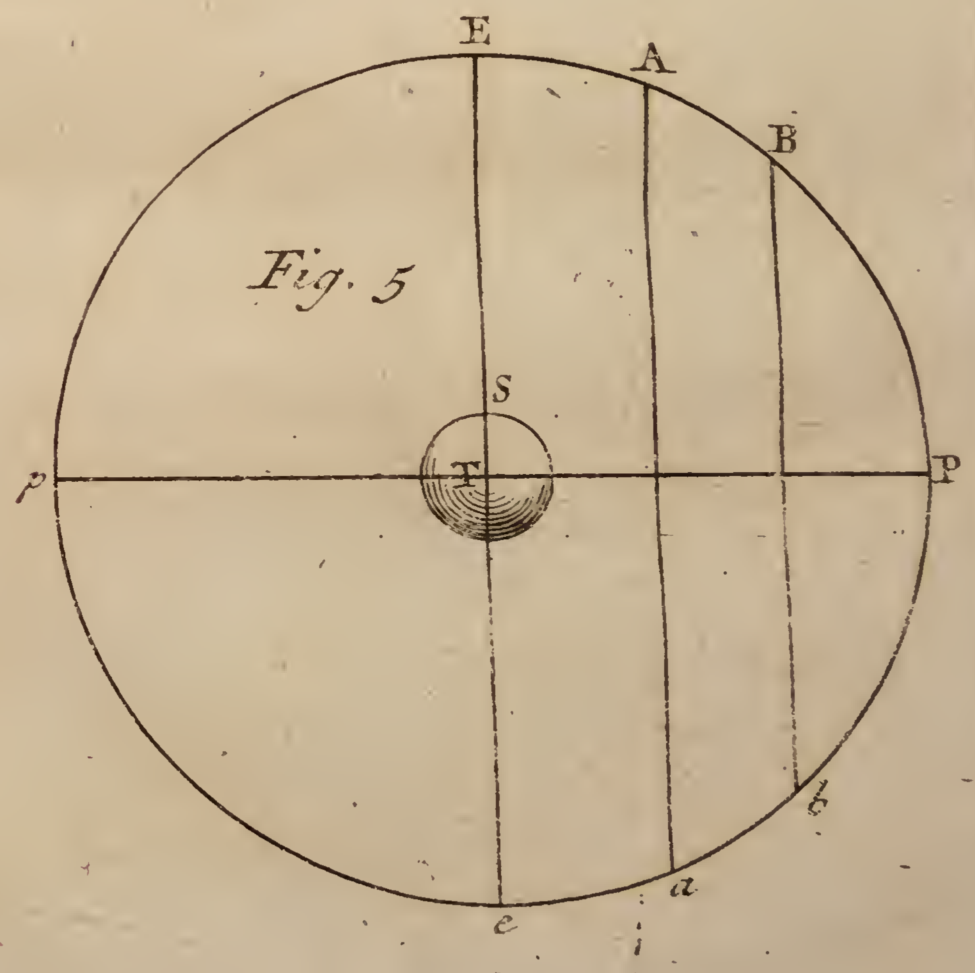

B
Z
A
P
E
S
H
H
h
T
h
a
e
p
N
i

Fig. 5


E
A
B
S
p
T
P
b
a
e

Vol. 2.

*the Æuator, towards either Pole;** for the Sun *1131
recedes from the Æquator towards the Poles 1132
23 Deg. 29 Min.* *1087

The Sun is in the Æquator about the 11*th of* 1088
March, *and the* 12*th of* September, *and then the* 1154
*Day is equal to the Night,** *which happens all over* *1194
the Earth, except juſt at the Poles.

DEFINITION XX.

Thoſe Points of the Ecliptic in which it is cut by 1155
*the Æquator,** *are call'd the* Æquinoctial *Points*;* 1085
becauſe the Sun is in thoſe Points when the above-mention'd Equality of Day and Night happens.

DEFINITION XXI.

*Theſe Points of the Ecliptic, in which the Tropicks touch that Circle,** *are call'd the* Solſticial *Points*;* 1089
Becauſe for a few Days, when the Sun comes to thoſe Points, and goes beyond them, it does not ſenſibly change its Declination, and the Length of the Days does not ſenſibly vary.

Under the Poles, if there be any Inhabitants 1156
there, they can only once in a Year ſee the riſing and the ſetting Sun, and *only one Day with one Night make up their whole Year.* The Sun continues above the Horizon all the while it goes
thro' one half of the Ecliptic;* the reſt of the *1085
Time it is hid under the Horizon. But yet 1123
*their Day is lengthen'd upon account of the Refraction,** 1157
and the Twilights laſt very long, for they laſt as 1113
long as the Declination of the Sun towards the hidden Pole does not exceed 18 Deg.* *1151

At the Arctic Pole, in the firſt ſix Signs, from 1158
Aries to *Libra*, the Sun is above the Horizon; therefore at that Pole *the Day exceeds the Night*
*nine Natural Days,** *beſides the Diminution of the* *1000
*Night on Account of the Refraction.** *1157

Theſe general Things which relate to the dif-
ferent Poſitions of the Horizon being explain'd,
ſome more particular Things are to be examin'd.

1159 *The whole Surface of the Earth is divided into five*
Zones. The firſt *is contain'd between the two Tro-*
1160 *pics* T T, *t t*, (Plate XXIV. Fig. 2.) *and call'd*
the Torrid Zone; *there are* two Temperate
Zones, *and* two Frigid Zones. The Northern
Temperate Zone *is terminated by the* Tropic of
Cancer T T, and the Arctic Polar Circle A A.
1161 The Southern Temperate Zone *is contain'd* be-
tween *t t*, the Tropic of *Capricorn*, and the Polar
1162 Circle *a a*. *The Frigid Zones are circumſcrib'd by*
the Polar Circles, and the Poles are in the Centers of
them.

1163 *In the Torrid Zone, twice a Year the Sun goes thro'*
*1137 *the Zenith at Noon*.* For the Elevation of the
1160 Pole is leſs than 23 Deg. 29 Min. and the Di-
1127 ſtance of the Sun from the Æquator towards the
Pole which is above the Horizon, is twice in a
1087 Year equal to the Height of the Pole. For
1088 which Reaſon alſo in the Limits of that Zone,
1164 namely, *under the Tropics, the Sun comes to the*
*1087 *Zenith only once in a whole Year*.*

1089 *In the Temperate and Frigid Zones*, the leaſt
1165 Height of the Pole exceeds the greateſt Diſtance
1087 1161 of the Sun from the Æquator; and therefore
1162 to their Inhabitants *the Sun never goes thro' the*
1166 *Zenith*.* Yet *the ſame Day the Sun riſes to a greater*
*1137 *Height, the leſs the Height of the Pole is*; becauſe
thereby the Inclination of the Circles of the
Diurnal Motion with the Horizon is leſs.

1167 *In the Torrid Zone, and in the Temperate Zones,*
*1129 *every Natural Day the Sun riſes and ſets*;* for the
1137 Diſtance of the Sun from the Pole always ex-
1168 *1087 ceeds the Height of the Pole.* Yet *every where*
1160 *but under the Æquator** *the Artificial Days are unequal*
1161 *to one another*;* which Inequality is ſo much the
*1152 *1132 greater

greater, the leſs the Place is diſtant from a Frigid Zone.* *1134

1169 But *in the Polar Circles*, juſt where the Temperate Zones are ſeparated from the Frigid ones, the Height of the Pole is equal to the Diſtance of the Sun from the Pole, when it is in the neighbouring Tropic;* and therefore in that Caſe, *1089 that is *once a Year, the Sun in its diurnal Motion* 1091 *performs one entire Revolution, without going down under the Horizon.*

1170 But *every where in a Frozen Zone* the Height of the Pole is greater than the leaſt Diſtance of the Sun from the Pole;* therefore, *during ſome Revo-* *1089 *lutions of the Earth, the Sun* is at a diſtance from 1162 the Pole which is leſs than the Pole's Height, and during all that Time, it *does not ſet*, nor ſo much as touch the Horizon.* But where the Diſtance *1135 from the Pole, as the Sun recedes from it, does exceed the Height of the Pole or Latitude of the Place,* the Sun riſes or ſets every Natural *1127 Day;* then in its Motion towards the oppoſite *1129 Pole, *it ſtays in the ſame manner below the Horizon*, 1171 as was ſaid of the Motion *above the Horizon.** *1136

These Times, in which the Sun makes entire Revolutions above the Horizon, and below it, in its Diurnal Motion, are ſo much the greater, that is, *the longeſt Day and Night laſt the longeſt, the leſs the Place in the Frigid Zone is diſtant from* 1172 *the Pole*, till at laſt at the Pole itſelf they take up the Time of the whole Year.

From the ſame Cauſes, namely, the Obliquity of the Ecliptic in reſpect of the Æquator, by which are occaſion'd all the Things which relate to the Inequality of Days which is different in different Places; we alſo deduce the Difference of Seaſons, which ſucceed one another every Year; I ſhall ſpeak of them firſt in re-

reſpect to the Frigid and Temperate Zones, and then in reſpect to the Torrid Zone.

The Rays of the Sun communicate Heat to the Air, not only when they come directly from the Sun, but when they are reflected irregularly
* 582 from Bodies or the Surface of the Earth.*

This Effect is ſo much greater as the Rays ſtrike the leſs obliquely againſt the Surface of the Earth; and that upon a double account. 1. If you reſolve the Motion of the Light into
* 192 two Motions,* one of which is parallel, and the other perpendicular to the Surface of the Earth; the Light acts upon Bodies only by this laſt Motion, which diminiſhes as the Obliquity encreaſes. 2. There are more Rays acting at one Time upon the ſame Part of the Surface of the Earth, the more directly they come upon it.

1173 Hence we deduce, that *the Cauſes of Heat encreaſe when the Days encreaſe*, by the Sun coming towards that Pole which is above the Horizon; becauſe the Sun does daily aſcend to a greater Height; ſo that to the diminiſh'd Obliquity is added the longer Continuance of the Sun above the Horizon, both which concur to the encreaſing of the Heat; the Nights alſo are diminiſh'd as the Days encreaſe, and the Heat that is produc'd by Day has leſs Time to decreaſe in.

In the Northern Zones, as follows from this, the Cauſe of Heat is the greateſt of all, when
*1090 the Sun comes to the Tropic of *Cancer*.* *Yet*
1174 *the Heat is not always the greateſt where the Cauſe of Heat is the greateſt*; for the Heat encreaſes as long as that which is acquir'd by Day is not wholly deſtroy'd by Night; for tho' the daily Augmentations be diminiſh'd, as long as there is an Augmentation the Heat encreaſes.
1175 So alſo the moſt intenſe Cold is not upon the ſhorteſt

ſhorteſt Day, in which the Obliquity of the Sun's Rays is the greateſt, and the Abſence of the Sun the longeſt; but the Cold encreaſes, as long as the Diminution of Heat does laſt; concerning which one may reaſon in the ſame manner, as concerning the encreaſe of Heat.

The Year is divided into four Seaſons; the hotteſt is call'd the Summer; the coldeſt the Winter; the temperate Seaſon that follows the Winter, Spring; and the Autumn comes in between Summer and Winter. 1176

In the Northern Regions, in the beginning of Spring, the Sun appears to be in the beginning of Aries: *in the beginning of Summer the Sun comes to the Tropic of* Cancer. *When the Sun enters* Libra, *the Autumn begins: in the beginning of Winter the Sun performs its diurnal Motion in the Tropic of* Capricorn; all which may be eaſily deduc'd from what has been explain'd. * 1177 *1174 1175

In the Southern Regions, the Summer happens in the Time of the Winter abovemention'd, and they have their Spring whilſt the former have their Autumn; and ſo of the other Seaſons. 1178

The general Cauſes upon which the Diviſion abovemention'd depends, are often diſturb'd by Cauſes relating to particular Place; eſpecially *in the Torrid Zone,* of which we ſaid we muſt treat of ſeparately. In moſt Places of this Zone *there are only two Seaſons obſerv'd,* (viz.) *Summer and Winter, which are* chiefly *diſtinguiſh'd by dry and wet Weather.* 1179

When the Sun comes to the Zenith of any Place, there are almoſt continual Rains, upon which account *the* Heat is diminiſh'd, which *Time is referr'd to, or call'd Winter.* As the Sun recedes, the Rains diminiſh, *the Heat is encreaſed, and that Time is referr'd to Summer.* 1180 1181

1182 *In the middle of the Torrid Zone, there are two Summers, and as many Winters; becauſe the Sun*
* 1163 *comes up twice to the Zenith.* *

Towards the Sides of this Zone, tho' the Sun comes twice to the Zenith; yet ſince there is but a ſmall Time between its coming to it the firſt and ſecond Time, both the Winters are confounded into one; wherefore only two Seaſons in a Year are obſerv'd there.

CHAP. IX.

Concerning the Phænomena ariſing from the Motion of the Axis of the Earth.

WE have ſaid that the Axis of the Earth
* 952 is carried by a parallel Motion *; we have not conſider'd a ſmall Motion, whereby it is really mov'd, of which we ſhall now ſpeak.

1183 *The Axis of the Earth, keeping the Inclination of* 66 Deg. 31 Min. *to the Plane of the Ecliptick, revolves in* Antecedentia, that is, is ſucceſſively carried towards all Parts; and its Extremities,
1184 *(viz.) the Poles of the World deſcribe Circles round the Poles of the Ecliptic,* from Eaſt to Weſt. And *this Revolution is perform'd in the Time of about* 25000 *Years, which Period is called the Great Year.*

Becauſe the Earth is look'd upon as immoveable by its Inhabitants, this Motion is referr'd to the heavenly Bodies, as has been ſaid of the other Motions. Therefore whilſt the Poles of the World are mov'd about the Poles of the Ecliptic in *Antecedentia*, and paſs ſucceſſively thro' all the Points that are 23 Deg. 29 Min. diſtant from theſe Poles, theſe Points themſelves, or rather the fixed Stars that are in them, come towards the Poles of the World ſucceſſively, and ſeem to be carried in *Conſequentia*, and to deſcribe Circles which are really deſcribed by the Poles of the World about the Poles of the Ecliptic, which, being plac'd in Centers, alone are at reſt. For together with the Stars abovemention'd, the reſt of the Stars (becauſe they keep the ſame ſituation in reſpect to one another) * do alſo appear to be moved. * 923

Therefore *the* whole *Sphere of the fix'd Stars, ſeems to move in* Conſequentia *about an Axis paſſing thro' the Poles of the Ecliptic*; and each Star apparently deſcribes a Circle parallel to the Ecliptic; by which Motion the Latitude of the Stars is not chang'd. 1185

The Plane of the Æquator makes a right Angle with the Axis of the Earth; therefore, by the aforeſaid Motion of its Axis, the Section of the Plane of the Æquator with the Plane of the Ecliptic, is mov'd round; wherefore *the firſt Points of* Aries *and* Libra *, which are always oppoſite, *move thro' the whole Ecliptick Line in the Space of about* 25000 *in* Antecedentia: yet they are look'd upon as immoveable by the Inhabitants of the Earth, who imagine that the fix'd Stars themſelves are mov'd in *Conſequentia.* * 1186 * 1085 * 1185

CHAP. X.

Concerning the fix'd Stars.

WE have ſaid that the fix'd Stars are lucid Bodies, remov'd ſo far off, that their Diſtances can be compar'd with no Diſtances in

1187 the Planetary Syſtem. For *Aſtronomers have not been able by their niceſt Obſervations, to obſerve the Poles of the World carried out of their Place in the annual Motion of the Earth,* altho' they deſcribe Circles in the Heavens which are equal to the
* 952 Earths Orbit. *

Definition I.

1188 This Motion of the Pole is call'd *the Annual Parallax.*

That the fix'd Stars are at an immenſe Diſtance, is alſo prov'd by Obſervations with the help of
1189 Teleſcopes. *If any fix'd Star,* even the moſt lucid and conſpicuous, *be beheld with a Teleſcope,* thro' which the Diameter of the Sun wou'd appear equal to the Diameter of the Earth's annual Orbit, *it will appear to be a lucid Point, without any ſenſible Magnitude*; for all the fix'd Stars appear leſs when they are ſeen thro' Teleſcopes, than they do to the naked Eye; for it is only their Twinkling which makes them appear to have any ſenſible Magnitude.

1190 *That the Stars may be diſtinguiſhed, they are referred to various Figures, which are imagin'd in the Heavens, and are call'd Conſtellations.*

1191 *Twelve Conſtellations are imagin'd to be in the Zodiac, which are call'd the Signs of the Zodiac*; they receive their Names from the Animals or Things
1192 which they repreſent: *Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpius, Sagittarius, Capricornus, Aquarius, Piſces.* Theſe Signs have *given their Names to twelve Parts of the Ecliptic,* of which
* 999 we have ſpoken before. *

In the Time of *Hipparchus,* the Sections of the Ecliptic and Æquator were between the Conſtellations of *Piſces* and *Aries,* and *Virgo* and *Libra,* and the Conſtellations gave their Names to thoſe

Parts of the Ecliptick, which paſs'd thro' each
Conſtellation: *And the Parts of the Ecliptic, ſuppoſing* 1193
the beginning of Aries *and* Libra, *in the Interſections
of the Æquator and the Ecliptic, have kept the Names
which they had* at that Time, *tho' theſe Interſections
be carried from their old Places**; whence the Sun* 1186
is ſaid to be in *Taurus*, when it moves amongſt
the Stars of the Conſtellation *Aries*.

The Zodiac ſeparates the North Part of the Heavens from the South Part.

In the Northern Region are the following Conſtellations; the Leſſer Bear, the Greater Bear, the Dragon, Cepheus, the Hounds, Bootes, the Northern Crown, Hercules, the Harp, the Swan, the Lizzard, Caſſiopeia, Camelopardus, Perſeus, Andromeda, the Triangle, the leſſer Triangle, the Fly, Auriga, Pegaſus, or the Flying-Horſe, Equuleus, the Dolphin, the Fox, the Gooſe, the Arrow, the Eagle, Antinous, Sobiesky's Shield, Serpentarius, the Serpent, Mount Mænalus, Berenice's Hair, the Leſſer Lion, the Linx.

*In the Southern Region of the Heavens, are the fol-
lowing Conſtellations, many of which are inviſible, to us:*** 1131
*namely, the Whale, the River Eridanus, the Hare,
Orion, the great Dog, Rhinoceros, the leſſer Dog, the
Ship Argo, Hydra, the Sextant of Urania, the Cup,
the Crow, the Centaur, the Wolf, the Altar, the
Southern Crown, the Southern Fiſh, the Phœnix, the
Crane, the Indian, the Peacock, the Bird of Para-
diſe, the Southern Triangle, the Croſs, the Fly, the
Chamœleon, King* Charles's *Oak, the flying Fiſh, the*
Toucan, *or* American *Gooſe, Hydrus, or* the Water-
Serpent, *Xiphias, or the* the Sword-Fiſh.

DEFINITION II.

The Stars, which are between the Conſtellations, are 1196
call'd unform'd Stars.

All the Stars are not equally lucid, and they are 1197
referr'd by Aſtronomers *to ſix Claſſes*, the moſt lu-
cid

cid are call'd Stars of the firſt Magnitude others are ſaid to be Stars of the ſecon Magnitude, others of the third, *&c.* to the ſixth Magnitude.

1198 *Some are not referr'd even to this laſt Claſs, and ar call'd Nebulous Stars.*

1199 *There is* alſo *a* certain *Zone* or Belt obſerv'd *in*
the Heavens, which is not every where of the ſame
Breadth, and goes round the whole Heavens
and in ſome Places is ſeparated, ſo as to become
double. From its Colour it *is call'd the milk*
1200 *Way. It* is plain from Obſervations, by the help
of the Teleſcope, that this Way is *an Aſſemblage*
of innumerable fix'd Stars, which cannot be ſeen by the
naked Eye, either becauſe they are leſs than the
other Stars, or more diſtant.
1201 *Towards the Antarctic Pole there are two Nubeculæ,*
of the ſame Colour as the Milky Way, which are alſo
heaps of ſmall Stars, and cannot be ſeen without
a Teleſcope. Beſides the Stars, which are ob-
ſerv'd in theſe Nubeculæ, and in the Milky Way,
1202 *to whatſoever Part of the Heavens you point the Tele-*
ſcope, you may diſcover ſmall Stars in a great Number,
which are not viſible to the naked Eye. Very often
an heap of Stars appears to the naked Eye to be
but one Star.

1203 *Amongſt the Stars, ſome are viſible and inviſible by fits, and obſerve regular Periods*; others are ſucceſſively ſometimes more lucid, ſometimes of a duller Light, and to be ſeen only by the help a Teleſcope, and that at certain Times.

1204 Yet *they are not equally bright at every Period.*

Sometimes Stars have appear'd ſuddenly, exceeding the brighteſt in Light, which afterwards ſucceſſively decreaſing, have vaniſh'd in a ſhort Time, and ſtill remain inviſible.

1205 Beſides the Stars, *we obſerve in the Heavens ſeveral whitiſh Spots, which are in ſome meaſure lucid, and*

and inviſible to the naked Eye; their Light is referr'd to the Stars which are in them, or they are look'd upon as nebulous Stars.

What theſe Spots are, cannot be determin'd, perhaps they are a Congeries of Stars, which have the ſame Relation to the Teleſcopic Stars, as thoſe which form the Milky Way, have to thoſe which are ſeen by the naked Eye.

BOOK IV.

PART II.

The Phyſical Cauſes of the Celeſtial Motions.

CHAP. XI.

Concerning univerſal Gravity.

HAving explain'd the Motions of the heavenly Bodies, and the Phænomena ariſing from them, we muſt now examine by what Laws theſe Motions are perform'd.

We have before laid down the Laws according
* 124 to which the Motions of Bodies are directed. *
125 If we add one to theſe, we ſhall ſee the whole
126 Contrivance by which that vaſt Machine the
Planetary Syſtem is govern'd.

1206 The Law to be added to the reſt, is this. *All Bodies are mutually heavy* (or gravitate) *towards*
1207 *each other. This Gravity is proportional to the Quan-*
1208 *tity of Matter: At unequal Diſtances it is inverſly as*

the Square of the Diſtance: That is, all Bodies mutually attract or tend towards each other, with the Force which belongs to each Particle of Matter acting upon each Particle; and the Force, with which a Body acts upon others, is compounded of the joint Forces of all the Particles of which the Body conſiſts; ſo this Force encreaſes in the ſame Proportion as the quantity of Matter, and is unchangeable in every Particle; it is always the ſame at the ſame Diſtance; but the Diſtance encreaſing, the Force decreaſes as the Square of the Diſtance increaſes.

1209 *We call this Force Gravity, when we conſider a Body which of it ſelf tends towards another*; becauſe this Force is call'd by this Name near the Earth's Surface. * *73

1210 *But when we conſider a Body, towards which another tends, we call this Force Attraction.* We mean the ſame Effect by theſe Names, and nothing but the Effect; for ſince all Gravity is reciprocal, * it is the ſame to ſay, all Bodies gravitate mutually towards one another, as that Bodies mutually attract one another, or mutually tend towards each other. *126

We look upon this Effect as a Law of Nature *, becauſe it is conſtant, and its Cauſe is unknown to us, and cannot be deduc'd from Laws that are known, as we ſhall ſhew by and by. Now that there is ſuch a Gravity, is to be prov'd from Phænomena. *4

All the primary Planets are kept in their Or-
bits by Forces, which tend towards the Center
of the Sun *; therefore there is a Force by *944
which the Planets are carried towards the Sun, 226
and whereby the Sun tends reciprocally towards
each of them *: *That is, the Sun and Planets* 1211
gravitate mutually towards each other. *126

After

1212 After the ſame manner 'tis plain, that *the Satellites of Jupiter and Jupiter gravitate towards each other; as alſo that the Satellites of Saturn gravitate towards their Primary Planet, and that towards them.**

* 966 226 126

1213 *The Moon and the Earth* alſo *gravitate towards each other.**

* 966 226 126

1214 *All the Secondary Planets gravitate towards the Sun.* For they are all carried by a regular Motion about their Primary Planets, as if the Primary Planets were at reſt; whence it is plain, that they are carried about by the common Motion with the Primary Planets; that is, that the ſame Force by which the Primary Planets are every Moment carried towards the Sun, acts upon *the Secondary ones*, and that they *are carried*

1215 *towards the Sun with the ſame Celerity as the Primary Planets.* Even the Irregularities of the Secondary Planets, which are ſo ſmall, as only to be ſenſible with reſpect to the Moon, confirm this Gravity of the Secondary Planets towards the Sun; for we ſhall ſhew herereafter that all the Irregularities are caus'd by the Change of the Moon's Gravity towards the Sun, at a different Diſtance; and becauſe the Lines in which the Earth and Moon tend towards the Sun are not altogether parallel.

1216 From the Gravity of the Secondary Planets towards the Sun, it follows, that *the Sun gravitates towards them.**

* 126

1217 In reſpect of the Gravitation of the Primary Planets towards one another, Aſtronomers have obſerv'd, that *Saturn* changes its Way when it is neareſt to *Jupiter*, which is far the greateſt of all the Planets; ſo that it is plain from immediate Obſervations, that *Jupiter and Saturn gravitate towards each other.*

Jupiter alſo in this Caſe, as *Flamſteed* has obſerv'd, 1218
diſturbs the Motion of *the Satellites of* Saturn,
attracting them a little to itſelf; which
proves that theſe Satellites *gravitate towards* Jupiter,
and Jupiter *towards them*. From all which
Conſiderations * compar'd together, it follows, *1211
that the ſeventeen Bodies, of which the Planetary 1212,
Syſtem is made up, mutually gravitate towards 1213,
each other, altho' no immediate Obſerva- 1214,
tions can be made concerning the Gravitation 1216, 1217,
of each particular one towards the reſt.* 1218.

The ſecond Part of the Law is,* that Gravity *7
is proportional to the Quantity of Matter; *1207
that is, that all the Particles of Matter gravitate
towards each other; and therefore that the Law
of Gravity is univerſal, and that every Body acts
upon all other Bodies; which is deduc'd from
Phænomena.

The Forces of Gravity are as the Quantities 1219
of Motions which they generate,* and theſe *58
Quantities, in unequal Bodies that are equally
ſwift, are to one another as the Quantities of
Matter;* therefore ſince unequal Bodies at the *62
ſame Diſtance from the attracting Body, move
equally ſwift by Gravity,* it is evident, that *1215
the Forces of Gravity are proportional to the
Quantity of Matter. We find the ſame in all 1220
Bodies *near the Earth's Surface*, which have a
Gravitation towards the Earth, proportional to
their Quantity of Matter.* But *the mutual Gravity* *79
of all theſe *Bodies towards one another is not*
ſenſible; becauſe it is exceeding ſmall in reſpect
of their Gravity towards the Earth; and therefore
cannot diſturb their Motion ariſing from
their Gravity towards the Earth;* at leaſt, ſo *190
as to make any ſenſible Change in the Direction
of their Motions.

We ſhall preſently ſhew, by another Method, that this univerſal Gravity of all the Particles of Matter whereby they act upon one another, *1222 may be prov'd from Phænomena.*

The third Part of the Law, which we examine, is, that Gravity decreaſes when the Diſtance encreaſes, and is inverſly as the Square of the Diſtances, which alſo follows from Phænomena.

1221 Bodies, upon which Gravity acts according to their Quantity of Matter, as in our Syſtem, are mov'd with an equal Celerity in the ſame Circumſtances, as we ſaid before; ſo that it is no matter, whether the Bodies are greater or leſs; and they are mov'd as if they were equal. But in this Caſe, if the Force towards a Point decreaſes in an inverſe Ratio of the Square of the Diſtance from that Point, and the Bodies move at various Diſtances from it, and are kept in Circles by that Force; the Squares of the Periodical Times will be to one another, as the *239 Cubes of the Diſtances.* Which is demonſtrated by Geometers to obtain (in reſpect of the Mean Diſtances) in Elliptic Lines, whoſe Forces are directed to their *Foci.* But this is the Caſe in Bodies which revolve about the *Sun,* *974 *Saturn* and *Jupiter*;* whence it follows, that the Force of Gravity, receding from the Centers of theſe Bodies, decreaſes in an inverſe Ratio of the Squares of the Diſtances.

1222 By this Reaſoning; ſuppoſing Gravity proportional to the Quantity of Matter, we demonſtrate, that it decreaſes in an inverſe Ratio of the Square of the Diſtance. And by the ſame Reaſoning; ſuppoſing the Diminution of Gravity to be in this Proportion, it follows, that Gavity is proportional to the Quantity of Matter, as is very evident.

But we prove by another Argument, that the Diminution of Gravity, ſo often mention'd, is in an inverſe Ratio of the Square of the Diſtance; ſo that there can remain no Doubt concerning the two Laws of Gravity which we now treat of.

The Planets are mov'd in Orbits at reſt;* 1223
and are kept in them by Forces, which are * 929
directed to an Excentric Point;* but it is plain, * 931
that this wou'd not obtain, if the central Force
did not encreaſe in an Inverſe Ratio of the Square * 241,
of the Diſtance.* 243

It follows from the ſame Reaſoning, that 1224
receding from the Center of the Earth, Gravity
decreaſes according to the ſame Law. For the
Moon is retain'd in its Orbit by a Force which
tends towards the Center of the Earth, that is,
to an Excentric Point:* And 'tho' the Line of * 967,
the Apſides is not carried by a parallel Motion, 966
its Agitation is ſo ſmall, if we conſider every 226
Revolution, that it may be look'd upon here as
quieſcent: For if we compute the Force which
keeps the Moon in its Orbit ſo agitated, we
ſhall find the Diminution of the Force of Gravity
in reſpect of the Moon, to differ very little
from an Inverſe Ratio of the Square of the Diſtance;
and we ſhall ſhew hereafter that this
Difference depends upon the Action of the Sun.

And no Doubt will remain concerning this 1225
Diminution, if we conſider, *that the Moon is kept
in its Orbit by that very Force, wherewith Bodies are
carried towards the Earth, near the Earth's Surface*;
which is diminiſh'd, according to the Law of
Diminution ſo often mention'd. The Mean Diſtance
of the Moon is $60\frac{1}{2}$ Semidiameters of the
Earth: We have before ſhewn, that a Diameter
of the Earth contains 3400669 *Rhynland*
Perches;* whence knowing the Periodical Time, * 976

we eaſily diſcover that the Moon in one Minute of Time, goes through $16425\frac{1}{2}$ *Rhynland* Perches of her Orbit. This Arc is not the hundredth Part of one Degree, and may be look'd upon as its Subtenſe; therefore the Diameter of its Orbit is to this Arc, as the Arc itſelf is to its Verſed Sine; which is diſcover'd to be of 15,736 *Rhynland* Feet; and it is the Space which the Moon and Earth wou'd go thro' in one Minute, coming to one another by their mutual Attraction. The Celerity with which a Body comes to another by the Force of Gravity, depends upon the Force with which it is attracted by that other, all whoſe Particles of Matter attract it; therefore the Celerities of the Moon and Earth, as they come towards each other, are inverſly as the Quantities of Matter in them; which is alſo deduc'd from the equal Quantity
* 126 of Motion that is in each Body.* Therefore
65 by this Proportion we diſcover how much of the aforeſaid Space (of 15,736 Feet) is gone thro' by the Moon; as the Quantity of Matter in both Bodies, is to the Quantity of Matter in the Earth: So is the Space gone thro' by both Bodies in their mutual Acceſs towards each other, to the Way gone thro' by the Moon only. The Quantities of Matter in the Moon and in the Earth, as we ſhall ſhew hereafter, are to one another as 1, to 39,37; and 40,37, is to 39,37, as 15,736 to 15,344, the Space gone thro' by the Moon; which therefore wou'd be gone thro' in one Minute by any Body, which at the Moon's Diſtance ſhou'd be impell'd by Gravity towards the Earth. This Force increaſing in an Inverſe Ratio of the Square of the Diſtance from the Center, the Space gone thro' in the ſame Time at the Diſtance of a Semidiameter of the Earth, that is, on its Surface, will be

$60\frac{1}{2}\times 60\frac{1}{2}\times 15{,}344$, (*viz.*) 56158 Feet; but becauſe in every Motion equably accelerated, as here (for we conſider the Force as remov'd from the Earth's Center to the Diſtance of its Surface) the Squares of the Times are as the Spaces gone thro' in the Fall;* by dividing the Number by *131
60×60, that is 3600; we have the Space gone thro' by a Body in one Second, near the Earth's Surface, by the Force with which the Moon is kept in its Orbit, which is diſcover'd to be 15,6. *Rhynland* Feet.

Now if we examine the Gravity which we daily find in all Bodies near the Earth's Surface,* it is plain, from what has been ſaid con- *72
cerning the Motion of Pendulums,* and from *157,
Experiments made upon Pendulums, that a Bo- 158
dy in falling goes thro' 15,6. *Rhynland* Feet in one Second of Time, and therefore falls with the Force by which the Moon is kept in its Orbit.

In this Computation we have neglected to conſider the Action of the Sun, becauſe it is ſmall, and ſometimes encreaſes, ſometimes diminiſhes the Gravity of the Moon towards the Earth.

We have conſider'd the Centers of Bodies in examining the Law of the Diminution of Gravity, altho' Gravity belongs to all the Particles of Bodies; becauſe it is plain by Mathematical Demonſtration, that *the Action of a ſpherical Bo-* 1226
dy (in which, in every Part, the Particles that are equally diſtant from the Center, are homogeneous, and which is made up of Particles, towards which there is a Gravity that decreaſes, receding from each of them in an Inverſe Ratio of the Square of the Diſtance) is directed towards the Center of the Body, and receding from it, is diminiſh'd in the ſame Inverſe Ratio of the Square of the Diſtance: So that ſuch a Body

acts, as if all the Matter of which it conſiſts,
was collected in its Center. Whence we deduce
the following Concluſions.

1227 That *on the Surfaces of Bodies, in which the
Matter is homogeneous at equal Diſtances from the
Center, the Gravity is directly as the Quantity of Matter,*
*1207, *and inverſly as the Square of the Diameter*;*
1208 for in theſe Bodies the Diſtances from the Center
are as the Diameters.

1228 That *on the Surfaces of Bodies that are ſpherical,
homogeneous, and equal, the Gravities are as the Denſities
of the Bodies*; for the Diſtances from the
Center are equal; in which Caſe the Forces of
1207 Gravity are as the Quantities of Matter;
228, which, in equal Bodies, are as their Denſities.
79 That *on the Surfaces of Bodies that are ſpherical,*
1229 *unequal, homogeneous, and equally denſe, the Gravities
are* inverſly as the Squares of the Diameters,*
*1208 becauſe the Diſtances from the Center are
*1207 *in the Ratio* of thoſe Diameters,* the Gravities
alſo are directly as the Cubes of their Diameters;
for the Quantities of Matter in Spheres
are in that Ratio: And the Ratio compounded
of that direct Ratio of the Cubes of the Diameters;
and the Inverſe Ratio of their Squares,
is the direct Ratio *of the Diameters themſelves.*

1230 Therefore, *if both the Denſities and the Diameters
differ, the Gravities on the Surfaces will be in a*
*1228 *Ratio compounded of the Denſities* and the Diameters.*
*1229 Therefore dividing the Gravity on the
Surface, by the Diameter, you will have *the*
1231 *Denſity*; which conſequently *is in a direct Ratio
of the Gravity on the Surface, and an Inverſe Ratio
of the Diameter.*

1232 *If a Body be plac'd in a Sphere that is homogeneous,
hollow, and every where of the ſame Thickneſs,*
whereſoever it be plac'd, *it has no Gravity,*
the oppoſite Gravities mutually deſtroying one
another

another preciſely : Whence it follows, that *in an* 1233
homogeneous Sphere, a Body coming towards the
Center, gravitates towards the Center only from
the Action of the Sphere, whoſe Semidiameter
is the Diſtance of the Body from the Center,
which *Gravity decreaſes in coming towards the Center,*
in the Ratio of the Diſtance from the Center ;* *1229
for all Matter, which is at a greater Diſtance
from the Center, forms an hollow Sphere, in
which the ſeveral Actions on a Body deſtroy
each other.* *1232

We have ſaid that the Gravity, which we
have hitherto explain'd, is to be taken for a
Law of Nature, becauſe we don't know the
Cauſe of it; and becauſe it depends upon no
Cauſe that is known to us, which will evidently
appear, if we attend to what follows.

(*Viz.*) That *Gravity requires the Preſence of the* 1234
attracting Body ; ſo the Satellites of *Jupiter*, *ex.*
gr. gravitate towards *Jupiter*, whereſoever it
be.* *1212

That *the Diſtance remaining the ſame, the Cele-* 1235
rity with which Bodies are carried by Gravity, de-
pends upon the Quantity of Matter in the attracting *1207
Body :* *And that the Celerity is not chang'd, let the* 1236
*Maſs of the gravitating Body be what it will.** *1207

Beſides that, *if Gravity depended upon any known* 1237
Law of Motion, it ought to be referr'd to a Stroke
from an extraneous Body; *and* becauſe Gravity is
continual, *a continual Stroke wou'd be requir'd.*

If there be ſuch a ſort of Matter continually
ſtriking againſt Bodies, it muſt of Neceſſity be
fluid, and very ſubtle, ſo as to penetrate all Bodies;
for Bodies that are any how ſhut up in
others, are heavy.

Now let a Mathematician conſider, whether
a Fluid ſo ſubtle, as freely to penetrate the Pores
of all Bodies, and ſo rare, as not ſenſibly to hinder

der the Motion of Bodies, (for in a Place void of Air, the Motion of a Pendulum will be continu'd very long) can impel vaſt Bodies towards one another with ſo much Force? Let him explain how this Force encreaſes in a Ratio of the Maſs of the Body towards which another is
1235 carried.

Laſtly, Let him ſhew, what ſeems moſt difficult to me, how all Bodies, in any Situation whatſoever (if the Diſtance, and the Body towards which the Gravitation is, remain the ſame)
1236 are carried with the ſame Velocity; that is, how a Liquid which can only act on the Surfaces, either of the Bodies themſelves, or their internal Particles, to which it is not hinder'd from coming by the Interpoſition of other Particles, can communicate ſuch a Quantity of Motion to Bodies, which in all Bodies exactly follows the Proportion of the Quantity of Matter in them; and which in this Chapter we have prov'd to obtain every where in Gravity, and which we have demonſtrated by a direct Experiment in
77 reſpect of the Gravity near the Earth's Surface.

1238 Yet we don't ſay, that *Gravity does not depend upon any Stroke*, but that it does not follow from that Stroke, *according to any Laws known to us*, and we confeſs that we are entirely ignorant of the Cauſe of Gravity.

CHAP. XII.

Of the Celeſtial Matter; where a Vacuum *is prov'd.*

HAVING explain'd the Laws whereby the whole Planetary Syſtem is govern'd, ſeveral Things muſt be firſt laid down, before we proceed to the Phyſical Explication of the

Syſtem. We muſt begin by ſaying ſomething of the Celeſtial Matter, that is, of the Medium in which the Bodies that make up the Syſtem are mov'd, which would be done in few Words, if all Philoſophers agreed that there is a *Vacuum.*

We have before prov'd that a *Vacuum* is poſſible;* now we are to demonſtrate that there is *13
really one. *From only conſidering Motion we can* 1239
deduce a Vacuum; and this is a very common and uſual way of proving it; to ſee the Force of which Argument, we muſt conſider, that indeed all Motions are not impoſſible without a *Vacuum,* but moſt of thoſe which are daily obſerv'd; which might be fully evinc'd by a longer Diſcuſſion: But it ſeems to me to be ſo evident from the following Conſideration, that it wou'd be uſeleſs to add much more.

The Figure of the leaſt Particles is unchangeable; for the Particle, whoſe Figure may be chang'd, conſiſts of ſmaller Particles, which are mov'd in reſpect to each other; and therefore if it has a changeable Figure, it is not one of the leaſt Parts.

But if the Figure of theſe Particles be unchangeable, and a Body can move between them, without ſuch a Separation of the Particles as to leave a void Space, this will depend on the Figure of the Particles, and the Relation which they have to one another, which a Mathematician will not deny: Therefore, if keeping Things in this State (as to their Figure and Relation) the Particles are encreas'd, even in that Caſe Bodies may be mov'd without a *Vacuum.*

Now ſuppoſing the ſmalleſt Particles encreas'd to the Bigneſs of a Cubic Foot, whatever be their Figure and Relation with the other Parts, which we ſuppoſe encreas'd in the ſame Proportion as the firſt; let any one conſider, whether

Bodies of any Bigneſs can be carried between thoſe Parts in Right Lines, and in all Sorts of Curves, and yet never ſeparate the Particles ſo as to leave Vacuities between them.

We cannot conceive how the moſt ſubtle Parts are made, and therefore often attribute to them ſuch Properties as do not follow from their Figure; but theſe Errors will be corrected, by imagining the Particles encreas'd.

1240 *We* alſo *prove a* Vacuum *by an Argument taken from Reſiſtance.*

* 12 We have ſaid that Matter is inactive;* ſome diſpute about the Word, but no Man denies the Thing; whence it follows, that a Body cannot move thro' a Fluid, without undergoing a Re-
* 319 ſiſtance,* and conſequently a Retardation.* The
* 330 Reſiſtance ariſing from the *Inertia* of the Matter, (which Reſiſtance alone is here conſider'd) depends upon the Quantity of Matter to be remov'd out of its Place, which is the ſame, whether the Parts of a Fluid be greater or leſs, if the Celerity of the Body remains the ſame: Whence it follows, that in determining what relates to the Reſiſtance, we muſt have no Regard to the Subtility of the Fluid, as long as it cannot go thro' the Pores of Bodies; for if we come to ſuch a Fineneſs of Parts, that a Fluid ſhall partly penetrate a Body, it will leſs reſiſt the Body.

Now let us ſuppoſe any Ball or ſpheric Body to be mov'd along in a Medium of the ſame Denſity as itſelf, and ſo cloſe, that the Parts of the Medium cannot paſs thro' the Pores of the Body; this Body will be retarded every Moment, ſo that its Velocity at laſt will be reduc'd to half; (as may be prov'd by a Mathematical Demonſtration) before the Body has gone thro' twice the Length of its Diameter.

In order to apply this Propoſition to a Motion in a very ſubtle Fluid, which freely penetrates the Pores of all Bodies, and fills all Places, we muſt conceive a ſpherical Body without any Pores at all; and that ſuch a Body may be ſuppos'd, by imagining all the Particles of Matter cloſely join'd, no Body will deny.

That the Reſiſtance of ſuch a Body in any Fluid does not depend upon the Bigneſs of the Parts of the Fluid, and is the ſame, whether the Parts of the Fluid be equal, or any how unequal, is evident.

If every Thing be full of Matter, this Body can only move thro' a Fluid of the ſame Denſity as itſelf; for it muſt run againſt all the Matter which is in thoſe Places thro' which it paſſes, and in them the Matter is without Interſtices as it is in the Body; therefore it will loſe half its Velocity before it has run through the Length of twice its Diameter.

Now let us ſuppoſe the Body to be encreas'd, the Quantity of Matter remaining the ſame, and the Body continuing homogeneous; that is, let there be Pores in the Body, thro' which the moſt ſubtle Particles of Matter may paſs very freely; and let theſe Pores be equally diſpers'd all over the Body. If the Body, thus chang'd, be mov'd, the very ſubtle Fluid of which we ſpeak will not run againſt the whole Surface, but only thoſe Parts of the Surface which are between the Pores, which Parts being taken together, becauſe we ſuppoſe the Body homogeneous, are equal to the Surface of the Body in the firſt Suppoſition, when we conceiv'd it to be without Pores; for the Body being encreas'd, the Surface has not been chang'd, but only dilated by the Interpoſition of Pores: So that in both Caſes the Body will undergo the ſame Reſiſtance from the impulſe upon the Surface; and the Reſiſtance on the dilated Body is greater from the Fluid running againſt the internal Parts of the Body. Wherefore this Body will ſooner loſe half its Motion in the ſecond, than in the firſt Caſe; that is, before it has run thro' the Length of two Diameters of the firſt ſuppos'd Bigneſs; and therefore it loſes a greater Quantity of Motion, in going thro' two Diameters of the Bigneſs ſuppos'd in the ſecond Caſe.

But this is contrary to Experience; for a homogeneous Ball of Gold, or Lead, *&c.* loſes a much leſs Quantity of Motion than what we have mention'd, in Water or Air; whence it follows, that the Suppoſition that all Things are full of Matter, is falſe. Therefore there is a *Vacuum.*

1241 *That there is a* Vacuum *does* alſo *agree with the Phænomena relating to Gravity*; by which it follows that it is proportional to the Quantity of Matter. If all was full of Matter, Gravity wou'd act equally every way, and the Forces which are directed towards oppoſite Parts wou'd deſtroy one another; and therefore no ſenſible Gravity wou'd be obſerv'd, which is contrary to Experience.

Theſe being premis'd, we muſt return to the Celeſtial Matter.

1242 The Motions of the heavenly Bodies do not depend upon the Motion of the Celeſtial Matter, if there be ſuch a Matter;* *whereby is overthrown the Opinion of thoſe which ſay that the heavenly Bodies are carried along by the common Motion of the Matter which fills our Syſtem.* This Opinion is alſo overthrown by the Motion of the Comets; if there was a Medium in the Syſtem which carried about the Planets in its Motion, and alſo the Comets, it wou'd at leaſt ſenſibly diſturb theſe laſt in their Motions, whilſt they come

* 1238

come almoſt directly towards the Sun, or directly recede from it, or are carried in *Antecedentia*; that is, in a Motion contrary to the Motion of that Matter: Now as this Motion is not diſturb'd, but follows the Way which depends upon Gravity, as it is obſerv'd, it is plain, that if there be any Cœleſtial Matter, and that is in Motion, it does not exert a ſenſible Action on the Bodies of the Planetary Syſtem, which is alſo deduc'd from the ſmall Reſiſtance of ſuch a Medium; for by comparing the moſt ancient Obſervations with the Modern, it does not appear that the Planets are ſenſibly retarded in their Motions. Yet in Air the Reſiſtance is ſenſible; wherefore the Denſity of the Medium in which the Planets ſhou'd move, muſt be almoſt immenſly leſs; therefore *the Planetary Syſtem* 1243
is not fill'd, unleſs it be *by* ſuch *a very ſubtle Medium.*

But we may from the Diviſibility of Matter deduce, that a Quantity of Matter, how ſmall ſoever it be, may be diſpers'd all over the Planetary Syſtem, leaving but very ſmall Interſtices.* *26

CHAP. XIII.

Concerning the Motion of the Earth.

BESIDES the Queſtion that has been handled in the foregoing Chapter, there is alſo another to be examin'd, before we proceed to the Explication of the whole Syſtem.

That no Doubt may remain concerning the Syſtem, which has been explain'd in the firſt Chapter of this Book, we muſt here prove the Motion of the Earth, concerning which it is no Wonder that many have doubted; for the Cœ-

leſtial Motions cannot be determin'd by us, but by Obſervations made by Obſervers on the Earth; and the ſame Phænomena appear, whether the Bodies themſelves be mov'd, or the
993 Spectator be mov'd; ſo that it is not to be prov'd by immediate Obſervations, whether the Motion of the Earth is to be referr'd to the heavenly Bodies or not.

1244 *That the Earth is carried about the Sun, is deduc'd form the Analogy of the Motions, and from an* Examen *of the Laws of Nature.*

As to what relates to the Analogy of the Motions, it is to be obſerv'd, that Satellites revolve about *Jupiter* and *Saturn*, which are leſs than the central Body; that the Moon revolves about the Earth, than which it is leſs; *Laſtly*, That the Sun has revolving about it leſs Bodies than itſelf, as *Mercury*, *Venus*, *Mars*, *Jupiter*, and *Saturn*: Now if the Earth revolves with the
1245 reſt, then every where *in our Syſtem the leſſer Bodies move about the greater*; now *there wou'd be an Exception in this Rule in reſpect of the Sun, if that* vaſt
*975 Body *was to go round ſo ſmall a Body as the Earth**.

About the Sun, *Jupiter* and *Saturn*, about which ſeveral *Bodies* revolve, thoſe *move the ſlow-*
1246 *eſt which are moſt diſtant from the central Body*, and according to this Rule, that the Squares of the Periodical Times follow the Ratio of the Cubes
974 of the Diſtances; *which Rule* may be applied to the Earth, if it be carried about the Sun with the reſt of the Planets, as appears, if its Periodical Time (namely the Time in which the Sun appears to perform an entire Revolution) and its Diſtance from the Sun be compar'd with the Diſtances and Periodical Times of the reſt of the Planets.

Now this Rule *has only one Exception, if the Sun being moved about, the Earth is at reſt.* In this

Caſe *Mercury*, *Venus*, *Mars*, *Jupiter*, and *Saturn*, are ſubject to this Rule in their Motions, as alſo the five Satellites of *Saturn*, and the four Planets that accompany *Jupiter*; only the Moon and the Sun wou'd move about the Earth in a Proportion quite different; and then the Celerity of the Sun wou'd not only be greater than is requir'd by this Law, but its Velocity wou'd at leaſt be ſix and twenty times greater than that of the Moon, tho' it be remov'd to a vaſt Diſtance from the Earth, in reſpect to the Moon's Diſtance: And therefore in this reſpect, the Analogy of the Celeſtial Motions wou'd be diſturb'd.

To theſe Arguments I ſhall add others, whereby it will clearly appear, that the Motion of the Earth is a neceſſary Conſequence of the Laws of Nature, which are deduc'd from Phænomena.

All Bodies gravitate towards one another,* 1247
therefore the Sun and Earth do; but the Mo- *1206
tion, whereby theſe Bodies tend towards one
another, is deduc'd from direct Obſervations.
Whichſoever of theſe Bodies moves about the
other, deſcribes Area's by Lines drawn to the
Center of it, proportional to the Times, which
is evident from Aſtronomical Obſervations;
therefore the Body mov'd is retain'd in a Curve
by a Force, which is directed towards the Cen-
ter of the other.* Now as Re-action is always *226
equal to Action,* unleſs the Laws of Nature, *126
which obtain conſtantly every where, be wholly
overturn'd, theſe two Bodies tend towards one
another with equal Motions; that is, with Ce-
lerities that are inverſly as their Maſſes;* which *65
is alſo immediately deduc'd from the Law of
Gravity.* *1235

The Quantity of Matter in the Earth is next to nothing, in compariſon to the Quantity of

Matter in the Sun, as we ſhall ſhew in the following Chapter; wherefore the *Sun muſt move very ſlowly, whilſt the Earth comes towards it very ſwiftly.*

Whence it follows, that the Earth is carried round the Sun, leſt it ſhou'd fall upon the Sun by that very violent Motion whereby it is retain'd in its Orbit.

This Motion of the Earth is alſo deduced from the ſame Principles, another way.

Two Bodies that are carried towards one another by any Force, will at laſt concur, or continually recede from one another, unleſs each of them be ſo mov'd, as to have a Centrifugal Force equal to the Force whereby it is carried towards the other Body; but as the Bodies which gravitate towards one another, tend to-
* 126 wards each other with equal Forces,* or what
* 65 is the ſame,* with Celerities that are inverſly as
* 1235 the Quantities of Matter;* theſe Bodies cannot
1248 perſevere in their Motions about one another, unleſs both of them be ſo mov'd, as to have equal centrifugal Forces, which does not happen, unleſs they both revolve in equal Times about their common Center of Gravity; that is, if this Propoſition be applied to the Sun and Earth, unleſs they both move about a Point, whoſe Diſtance from the Center of the Sun is to its Diſtance from the Center of the Earth, as the Quantity of Matter in the Earth is to the Quantity of Matter in the Sun, they cannot perſevere
* 234, in their Motions about one another:* This Point
235 or Center of Gravity muſt of Conſequence be very near to the Sun's Center. Now ſince whichſoever of theſe Bodies moves, it perſeveres in its Motion about the other, it follows, that both of them are affected by the Motions above-mention'd, and that the Sun is mov'd but

but a little, whilſt the Earth deſcribes a very great Orbit. Whence it follows, that the Motion of the Earth cannot be denied by any one who reaſons from the Laws of Motion that are deduc'd from Phænomena.

Having prov'd *the* annual *Motion of the Earth,* 1249
and brought back the Earth amongſt the Planets, there remains but little Difficulty in Relation to the Motion of it *about its Axis*; for no Body that believes the annual Motion, doubts of this; a great many which allow of the Motion about the Axis, deny the Annual Motion; therefore it will be enough to obſerve by the By, that all the Planets, concerning which any Obſervations cou'd be made in reſpect of this Motion, do move about their Axes; and that the Earth has ſuch a Motion, *the uniform diurnal Motion in Bodies at any Diſtances, does plainly enough ſhew.* To which we muſt add, that the Celerity of the fix'd Stars going thro' one whole Revolution in leſs than 24 Hours, can hardly be more probable than it is conceivable.

This Motion alſo is diſagreeable to the Na-
ture of all *the heavenly Bodies*; for, *if they are* 1250
carried round, they muſt every Day, with an
equable Motion, deſcribe Circles that have the
Earth for their Center; that is, they muſt, by
Lines drawn to the Center of the Earth, ſweep
thro' Area's proportionable to the Times, and
be retain'd in their Orbits by Forces which are
directed towards the Center of the Earth,* and * 226
by which (by reaſon that Action and Re-action* * 126
are equal) *the Earth* muſt alſo be continually at-
tracted towards thoſe Bodies; ſo that it *muſt ne-
ceſſarily be agitated by a very violent Motion*; whence
it appears that the diurnal Motion muſt not
be referr'd to the heavenly Bodies, but to the
Rotation of the Earth about its Axis.

1251 Thoſe that obſtinately affirm that the Earth is at reſt, object that Bodies, upon the Surface of the Earth, muſt (on account of their centrifugal Force) recede from the Earth, along a
* 217 Tangent to a Circle parallel to the Æquator.* We anſwer, that the Bodies in the Places where they are, are carried round with the ſame Motion as the Surface of the Earth; and therefore, that in reſpect of the Points of the Surface, they endeavour to recede in Lines perpendicular to
* 223 the Axis;* but alſo that Bodies by Gravity tend
* 1226 to the Center of the Earth;* and therefore by a Motion compounded of both theſe, the Body is
* 190, 198 continually mov'd, or endeavours to move;* but becauſe the firſt Motion is extremely ſmall in reſpect of the other, a heavy Body is turn'd but very little out of its Direction towards the Center, and the Gravity is a little diminiſh'd, ſo much the more as the Place is more diſtant from the Pole; which agrees with Experience. We ſhall hereafter ſhew, when we come to ſpeak of the Figure of the Earth, that the above-mention'd Direction of heavy Bodies, is every where directed perpendicularly to the Surface of the Earth. A Body which is thrown upwards, is acted upon not only by the Motion wherewith it is thrown up; but it is alſo carried by the Motion that is impreſs'd to the Perſon or Machine that impels the Body; that is, it is carried by the Motion which is common with the Surface of the Earth; and therefore the Body moves in the ſame Line (the Line being carried on with the Surface of the Earth) as it would do if the Earth was at reſt.

CHAP. XIV.

Concerning the Denſity of the Planets.

BEFORE we proceed to the Phyſical Explanation of the Syſtem, we muſt determine the Quantities of Matter in ſome Bodies, and their Diverſities; which being known, the Effects of the Laws by which theſe Bodies are govern'd, will more eaſily appear.

The Quantities of Matter in different Bodies, are to one another, as the Gravities at the ſame Diſtance from theſe Bodies;* which Gravities * 1207
are to one another inverſly as the Squares of the Periodical Times of the Bodies revolving about thoſe different Bodies at the ſame Diſtance.* * 236
By multiplying the Quantities which are in this Ratio, by the ſame Quantity, (*viz.*) by the Cube of this Diſtance, the Ratio of theſe Quantities will not be chang'd; which are therefore to one another as the Quotients of the Diviſions of the above-mention'd Cube, by the Squares of the Periodical Times aforeſaid: But the Quotient of ſuch a Diviſion is found for any Body, by dividing the Cube of the other Diſtance, let it be what it will, by the Square of the Periodical Time of the Body revolving at that Diſtance; for ſuch Quotients are equal to one another, for all Bodies that revolve about the ſame Body at any Diſtances; as follows from the Equality of the Ratio between the Cubes of the Diſtances, and the Squares of the Periodical Times at thoſe Diſtances.* From which we deduce, * 974
that *the Quantities of Matter in any Bodies in our* 1252
Syſtem, are to one another directly as the Cubes of the Diſtances at which other Bodies revolve about theſe,

and inverſly as the Squares of the Periodical Times of theſe revolving Bodies.

Theſe Things are demonſtrated by ſetting aſide the Agitation of the Central Body, whoſe Quantity of Matter is enquir'd after.

By reaſon of the Sun's Magnitude, in Reſpect of *Venus, ex gr.* which alone we conſider of the Planets, the Sun is ſcarce mov'd by the Action
1235 of that Planet. And *Venus* may be conſider'd as moving about a quieſcent Body.

The Satellites of *Jupiter* and *Saturn* are indeed carried by the common Motion along with the Primary Planets, but by reaſon of the Magnitude of the Primary Planets, they are carried about them as about Bodies that are at reſt.

But the Moon acts ſenſibly enough upon the Earth and moves it; wherefore before we can compute the Moon of the Motion by the Help
1252 of the aforeſaid Rule, in order to compare the
1253 Quantity of Matter in the Earth, with the Quantities of Matter in the Sun, *Jupiter*, and *Saturn*, we muſt determine *the Diſtance at which the Moon would move about the Earth*, if it was at Reſt (that is, *not carried about by the Action of the Moon,) in the ſame Periodical Time in which it now performs its Revolution.* Here alſo we don't take Notice of the Motion that is common to the Earth and Moon, by which they are both carried about the Sun.

The Moon perſeveres in its Motion about the Earth; therefore the Earth and Moon are mov'd about a common Center of Gravity; as follows from what has been demonſtrated concerning the
1248 Earth and the Sun, and the Moon (with that Force with which it tends towards the Earth,) revolves in an Orbit whoſe Semi-Diameter is the Diſtance of the Moon from the aforeſaid common

mon Center of Gravity of the Moon and the Earth.

Let L be this Diſtance of the Moon from the common Center of Gravity; T the Diſtance of the Earth from the ſame Center; $L + T$ therefore is the Diſtance of the Moon from the Earth, and is 60½ Semi-Diameters of the Earth; for here we conſider the mean Diſtance. Let D be the Diſtance which we would have, at which the Moon, by its Gravity towards the Earth, would move about the Earth, if it was at Reſt, in the ſame Time in which it is now mov'd about the common Center of Gravity at the Diſtance L.

By reaſon of this Equality of the Periodical Times, the Force whereby the Moon would be kept in its Orbit at the Diſtance D, is to the Force whereby it is kept in its Orbit at the Diſtance L, as D to L.* * 232

But the Force whereby the Moon would tend to the Earth, and be kept in its Orbit at the Diſtance D, is to the Force whereby it is now kept in its Orbit at the Diſtance $L + T$, as $\overline{L + T}^q$ to D^q *. Therefore *1208

$$D, L :: \overline{L + T}^q, D^q$$

Conſequently $D^c = L \times \overline{L + T}^q$, and $D^c \times \overline{L + T} = L \times \overline{L + T}^c$: Whence we deduce the following Proportion:

$$\overline{L + T}^c, D^c :: L + T, L.$$

Therefore $L + T, D :: L + T$, is to the firſt of two mean Proportionals between $L + T$ and L.

$L + T$, is to L, as the Quantity of the Matter in the Earth and Moon taken together, to the Quantity of Matter in the Earth alone; * which Quantities of Matter, as we ſhall ſhew hereafter, are to one another, as 40,37. to * 234, 235

39,37. and the firſt of two mean Proportionals to theſe Numbers is 40,035.; therefore 40,37. is to 40,035. as $60\frac{1}{2}$ to the Diſtance requir'd, which is found to be 60 Semi-Diameters of the Earth.

Concerning this Operation it is to be noted, that the Diſtance D cannot be diſcovered unleſs the Ratio between the Maſs of the Moon and the Earth be known, which cannot be determined unleſs the Ratio between the Denſity of the Sun and the Earth be found; to diſcover which, it is neceſſary that the Diſtance D be known. Wherefore D is diſcover'd at firſt by Trials, and is exactly determin'd by Approximation. But it is certain, that this is 60 Semi-Diameters of the Earth; becauſe, this being ſuppos'd, it is found that the Ratio between the Quantities of Matter of the Moon and the Earth is as 1 to 39,37. as we ſhall ſee hereafter; by making uſe of which Proportion, this Diſtance is diſcover'd to be 60 Semi-Diameters, as we have ſhewn.

Theſe Things being premiſed, we proceed to the Computation.

The Diſtance of *Venus* from the Center of the Sun is 723, and its Periodical Time is 5393 Hours.*
* 959

The Fourth Satellite of *Jupiter* is diſtant from the Center of *Jupiter* 12,507 ſuch Parts of which *Venus* is diſtant from the Sun 723. The Periodical Time of this Satellite is 402 Hours, 5 Minutes.*
* 971

The Fourth Satellite of *Saturn* is diſtant from the Center of *Saturn* 9,292 of the ſame Parts; and its Periodical Time is 382 Hours 41 Min.*
* 972

Laſtly, the Diſtance of the Moon is 60 Semi-Diameters of the Earth from its Center, and

2,909 of the aforeſaid Parts. Its mean Periodical Time is 655 Hours, 43 Min.

If you divide the Cubes of theſe Diſtances 1254
reſpectively by the Squares of their Periodical Times, you will have in the Quotients, Numbers which are to one another as the Quantities of Matter in the aforeſaid Central Bodies;* *1252
which Quotients are to one another as the following Numbers;

	In the Sun.	*In Jupiter.*	*In Saturn.*	*In the Earth.*
Quantities of Matter	10000.	9,248.	4,223.	0,0044.

We have alſo the Proportion of the Diameters 1256
of theſe Bodies from Aſtronomical Obſervations, as follows.

	Of the Sun.	*Of Jupiter.*	*Of Saturn.*	*Of the Earth.*
Diameters	10000.	1077.	889.	104.

If the Quantities of Matter aboveſaid be di- 1257
vided by the Squares of the Diameters, the Quotients will be to one another as the Weights on the Surfaces of the aforeſaid Bodies;* and *1227
theſe Quotients are as the following Numbers.

1258

	Of the Sun.	*Of Jupiter.*	*Of Saturn.*	*Of the Earth.*
Gravities on the Surfaces	10000.	797,15.	534,337.	407,832.

If you divide theſe Numbers by the Diame- 1259
ters, you will have the Proportion of the Denſities of thoſe Bodies.* *1231

The Quotients found by theſe Diviſions are as the following Numbers.

1260

	Of the Sun.	*Of Jupiter.*	*Of Saturn.*	*Of the Earth.*
Denſities	10000.	7404.	6011.	39214.

We ſhall determine the Denſity of the Moon in the laſt Chapter.

It is not probable that the aforeſaid Bodies are homogeneous. We ſhall ſhow in relation to the Earth, in the 17th Chapter, that it is denſer towards the Center than towards the Surface; from whence it follows, that the Denſities cannot be exactly determin'd, wherefore we only *determine the mean Denſities*, that is, *which*
1261 *the Bodies would have, if the ſame Bodies, keeping the ſame Quantity of Matter and Bulk which they now have, ſhould become homogeneous.*

1262 *The above-mention'd Proportion* between the Den-*
* 1260 *ſities, in reſpect of all the Bodies, and the reſt of the Computations in reſpect of the Sun, Jupiter, and Saturn, are free from any ſenſible Error; when they are compar'd with the Earth there may be ſome Error*, which muſt be corrected by Obſervations to be made hereafter; for we ſuppoſe the Diſtance of the Moon (which is 60 Semi-Diameters of the Earth) to be 2,909 ſuch Parts, of which *Venus* is diſtant from the Sun 723, that is, of
* 959, 960 which the Earth is diſtant from the Sun 1000;* which Diſtance of the Moon is diſcover'd by ſuppoſing the Horizontal Parallax of the Sun 10″, which cannot be look'd upon as abſolutely true, altho' it be deduc'd from the moſt exact Obſervations that have hitherto been made, of the Parallax of *Mars*, when it is neareſt of all to the Earth, which is too ſmall to leave us
* 1108 without Suſpicion of ſome Miſtake.*

But the Error in not determining truly the Proportion between the Semi-Diameter of the Earth and the Diſtance from the Sun, does not change the determin'd Denſity of the Earth, as is deduc'd from Computations made about it.

For it follows from theſe, that the Denſities of Bodies are to one another in a Ratio com-

pounded of the direct Ratio of the Cubes of
the Diſtances of the Bodies carried about, and
the inverſe Ratio of the Squares of the Periodical
Times of theſe revolving Bodies;* as alſo of* 1254
the inverſe Ratio of the Cubes of the Diameters
of the Central Bodies whoſe Denſities are
requir'd;* the Ratio compounded of theſe, is* 1257
compounded of the direct Ratio of a Fraction 1259
whoſe Numerator is the Cube of the Diſtance
of the revolving Body, and whoſe Denominator
is the Cube of the Diameter of the Central
Body, and the inverſe Ratio of the Square of the
Periodical Time of the Body carried about.
But you have ſuch a Fraction, if you know the
Ratio between the Diameter of the Central
Body, and the Diſtance of the revolving Body
from that Center, altho' this Diſtance can be
compar'd with no other; but this Ratio is given
in reſpect of the Earth and Moon, as well as in
reſpect of the other Bodies; wherefore alſo the
Ratio of the Denſity of the Earth to the Denſities
of the other Bodies is exactly diſcover'd.

CHAP. XV.

The Phyſical Explanation of the whole Planetary Syſtem.

IN the firſt Part of this Book we have ſhewn
what are the Motions of the Bodies in the * 124,
Planetary Syſtem; now we muſt explain how 125,
theſe Motions follow from the Laws of Nature;* 126,
that is, how theſe Bodies being once put in 1206,
motion, perſevere in thoſe Motions which we obſerve. 1207, 1208

Let us conceive the Sun and *Mercury* to be left 1263
to themſelves, and they will come together;* * 1206
but if they be projected, they may revolve about
a com-

a common Center of Gravity in equal Times, *1248 and deſcribe immoveable Ecliptic Lines;* and 1208 perſevere in that Motion; for it is plain, 241 by Mathematical Demonſtration in that Caſe, that the Bodies will deſcribe Ellipſes about the common Center of Gravity, ſimilar to that which one of them could deſcribe with the ſame Forces about the other, if it was at reſt: This Center, *235 on account of the Sun's Magnitude,* is very little diſtant from the Center of the Sun itſelf.

Let us conceive beſides, *Venus* to be projected at a greater Diſtance from the Sun, it will a little diſturb the Motion of *Mercury*, which alſo by its Action upon *Venus*, will turn it a little out of the Way, and both will draw the Sun, ſometimes the ſame Way and ſometimes different Ways; but we find all theſe Irregularities are inſenſible, if we conſider the Magnitude of the Sun; and therefore that theſe three Bodies tend towards a Point that is between them near the Sun, which therefore is very little diſtant from the common Center of Gravity of them all.

If the Earth, *Mars*, and the other Planets be ſucceſſively projected at different Diſtances from the Sun, the ſame Reaſoning will hold good. 1264 Whence it follows, that *all the Planets are revolv'd about the common Center of Gravity of all the Bodies, which compoſe the Syſtem*, which is but little diſtant from the Sun, and that the Planets do not ſenſibly diſturb one another in their Motions; 1265 wherefore *they all deſcribe the ſame Lines ſingly, which they would deſcribe about the Sun, if every one of them was alone with the Sun in the Planetary Syſtem*, that is, immoveable Ellipſes: For it is plain, that theſe will be deſcrib'd by the Force *1208 of Gravity;* and it is prov'd by Mathematical 241 Demonſtration, that no other immoveable excentric Lines can be deſcrib'd by a Central Force acting equally at equal Diſtances.

It will alſo more plainly appear, that all the Planets tend to a Point near the Sun, if we conſider that the Quantity of Matter in the Sun is a thouſand times, and more, greater than the Quantity of Matter in *Jupiter*, which is far the greateſt of all the Planets.* *1255

When all *the Planets move*, tho' they move *the* 1266
Sun but little, yet they do move it, and draw it differently according to their different Situation in reſpect of one another, whence there ariſes a ſmall Motion in the Sun, which always depends upon the Motion already acquir'd, and the Change which happens in it from the Action above-mention'd, which varies every Moment.

It is owing to this Agitation of the Sun, that the 1267
Planets diſturb one another leſs in their Elliptic Motions round the Sun, than if the Sun was at Reſt in the Middle of the Syſtem. If *Jupiter*, *ex gr.* was equally diſtant from *Mercury* and the Sun, it would attract both thoſe Bodies to itſelf with an equal Celerity,* whence the Situation in re- *1235
ſpect of the Sun is leſs chang'd than if the Sun was not agitated by this Motion, and *Mercury* only was attracted by *Jupiter*: According to the various Diſtances of *Mercury* and the Sun from *Jupiter*, the one or the other is more attracted, and there is always a leſs Change in their reſpective Situation when both are carried the ſame Way, than if (the Sun being at Reſt) *Mercury* only ſhould be carried towards *Jupiter*.

This Reaſoning may be applied to all the Actions of the Planets that are more diſtant from the Sun upon thoſe that are leſs diſtant. As to what relates to the Action of thoſe that are nearer, upon thoſe that are farther from the Sun, according to the different Situation they draw a Planet to the Sun, or drive it from the Sun, and in conſidering one whole reſpective Revolution, that is, the Motion from one Conjunction to another, the Diſturbance is leſs than if the Sun was immoveable.

1268 The Magnitude of the Sun, compar'd with the reſt of the Bodies of our Syſtem, is the Reaſon (as appears by what has been already demonſtrated) that the Planets diſturb one another but little; but ſince the Magnitude is not infinite, theſe mutual Actions muſt not be wholly overlook'd.

We have ſaid, that it appears by Aſtronomical Obſervations, that *Jupiter* alters the Way of
*1217 *Saturn* when it is neareſt to;* why this Diſturbance is more ſenſible than the reſt, is deduc'd from the Law of Gravity.

1269 The Actions of *Jupiter* upon *Saturn* when it is neareſt to it, and of the Sun upon the ſame Planet, by which it is kept in its Orbit, are to one another directly as the Quantities of Matter in
*1207 *Jupiter* and the Sun,* (*viz.*) as 9,248. to 10000,*
*1255 and inverſly as the Squares of the Diſtances of *Jupiter* and the Sun from *Saturn*, that is, directly as 81 to 16; for the Diſtances of *Saturn* and *Jupiter* from the Sun are almoſt as 9 to 5;
1270 wherefore, *when Jupiter is neareſt to Saturn, the* Diſtances of *Saturn* from *Jupiter* and the Sun are as 4 to 9. The Ratio compounded of the two aforeſaid Ratio's is as 749 to 160000, or as 1 to 214; this *Action of* Jupiter *conſpires with the Gravity of* Saturn *towards the Sun, and* therefore *encreaſes it* $\frac{1}{214}$ Part: Whence it is no Wonder that the Diſturbance is ſenſible.

We don't here conſider the Force by which *Jupiter* attracts the Sun, for the Orbit of *Saturn* is not chang'd by it, and what we had to explain was, why Aſtronomers obſerve *Saturn* to be turn'd out of the Way ; yet by the Action of *Jupiter* upon the Sun, the Sun is brought nigher to *Saturn*, and the reſpective Situation of theſe Bodies is more diſturb'd, than is diſcover'd by Aſtronomical Obſervations. The Force with which *Jupiter* in the aforeſaid Poſition attracts the Sun, and with which therefore the Sun is attracted towards *Saturn*, is to the Force with which *Jupiter* attracts *Saturn*, as 16 to 25 ; * that *1208 is, as 479 to 749, which Number expreſſes the Force with which *Saturn* tends towards *Jupiter*, when the Gravity of *Saturn* towards the Sun is expreſſed by 160000. If we collect into one Sum the Forces of *Jupiter*, by which it attracts *Saturn* and the Sun ; the Force, by which, from the Interpoſition of *Jupiter*, theſe Bodies tend towards each other, will be to the Gravity of *Saturn* towards the Sun, as 1228, to 160000 ; but this Gravity is to the Gravity of the Sun towards *1207 *Saturn*, as 160000 to 67,5. * wherefore *the* 1255 *mutual Acceſs or Approach of the Sun and* Saturn, 1271 *is to the Encreaſe of this Approach by the Action of* Jupiter *interpoſed*, as 160067 to 1228, or, *as* 130 *to* 1.

This Diſturbance is remarkable, and far the greateſt of any that happens in the Motion of any of the primary Planets ; this alſo obtains only in this one Caſe of the Conjunction ; for when *Jupiter* recedes from *Saturn*, the Diſturbance of the Motion of *Saturn*, in a ſhort Time, becomes inſenſible.

In the ſame Poſition of *Jupiter*, when it is neareſt to *Saturn*, the Force of *Saturn*, altho' it be the greateſt of all in this Caſe, does not ſo ſenſibly alter the Way of *Jupiter* about the Sun. The Action of *Saturn* attracting *Jupiter*, is to its Action by which it attracts the Sun, as 81 to 16 ; therefore it attracts *Jupiter* with greater *1208 Celerity ; and ſince they are both attracted the

ſame Way, the difference of theſe Forces is the
Force, with which (from the Action of *Saturn*,)
Jupiter and the Sun are ſeparated from each
*175 other *; which is therefore to the Gravity of
the Sun towards *Saturn*, as *65* to *16*; but this
Gravity of the Sun towards *Saturn*, is to the
Gravity of *Jupiter* towards the Sun, as 4,223. to
*1207 10000 *, and as 25 to 81 *, that is, as 106 to
1255 810000, or as 16 to 122756; therefore the
*1208 diſturbing Force of *Saturn* is to the Gravity of
Jupiter towards the Sun, as *65* to 122756, or
1272 as 1 to 1888; therefore *by the greateſt Action of* Saturn, *the Gravity of* Jupiter *towards the Sun is diminiſh'd only by* $\frac{1}{1888}$ *Part*, which diſturbance is
inſenſible.

The other mutual Diſturbances of the Planets are much leſs, as will appear by determining that, which is the greateſt of them all, (*viz.*) that of *Mars* by *Jupiter*, which is diſcover'd by the ſame ſort of Computation as the foregoing.

The Diſtance of *Jupiter* from *Mars* and the
Sun, when *Mars* is between the Sun and *Jupiter*
*961, 962 in the ſame Line, are as 7 to 10 *; wherefore
the Forces with which *Jupiter* attracts theſe
*1208 Bodies, are as 100 to 49 *, the Difference of
which Forces is to the Gravity of the Sun towards *Jupiter*, as 51 to 49. This Gravity of
the Sun towards *Jupiter*, is to the Gravity of
*1207 *Mars* towards the Sun, as 9,248 to 1000 *, and
1255 *1208 as 9 to 100 *; that is, as 83 to 1000000; or as
49 to 590443; and the diſturbing Force of *Jupiter* is to the Gravity of *Mars* towards the Sun,
as 51 to 590443; or as 1 to 11577: wherefore
1273 *the Gravity of* Mars *towards the Sun, is diminiſh'd only* $\frac{1}{11577}$ *Part by the Action of* Jupiter *when neareſt to it.*

Altho' theſe Diſturbances ariſing *from the* 1274
Actions of the Planets upon each other, be very ſmall,
and altho' thoſe which happen in a different Poſition
of the Planets, do in ſome Meaſure compenſate
each other, yet the Proportion in which
the Force, which keeps the Planets in their Orbits
decreaſes, is a little chang'd by theſe Actions,
ſo that it does not decreaſe exactly in an inverſe
Ratio of the Square of the Diſtance:
Therefore altho' the Orbits are at reſt as to
Senſe, *after a great many Revolutions, a ſmall change* * 243
is obſerv'd in their Situation. * 929

From all this it follows, that if we ſuppoſe the 1275
Planets at firſt once projected at the Diſtances
from the Sun at which they are mov'd, they
will by the Laws already explain'd, perſevere in
thoſe Motions; and the Excentricity of the Orbits
depends upon the Celerity and direction of
the firſt Projection. But theſe Motions may be
preſerv'd very long, by reaſon of the ſmall Reſiſtance
of the Celeſtial Matter.

It is alſo plain, why by Lines drawn to the
Center of the Sun, they deſcribe *Areas* proportionable
to the Times; namely, becauſe all other
Gravities in the Syſtem, are very ſmall in reſpect
to the Gravity towards the Sun *; therefore by * 1265
this Gravity alone, it is that they are retain'd in
their Orbits, whence follows this proportion of
the *Areas* *. And alſo Motion in Elliptic Lines, * 225
which are carried on very ſlowly, follows from the
Law of Gravity; and theſe Lines wou'd alſo be
immoveable, if the Planets gravitated only towards
the Sun *; but this ſlow Motion of the * 241
Orbits, is deduc'd from the Action of the Planets 1208
upon one another. * Now in reſpect to the * 1274
Proportion which is obſerv'd between the Cubes
of the Diſtances, and the Squares of the Periodical
Times, it is alſo deduc'd from the Law of
Gravity

* 239 Gravity ; * ſo that if we add to theſe what we
1208 have ſaid of the Deflection of *Saturn*, * nothing
* 1217
1270 will remain to be explain'd in reſpect to the Primary Planets.

1276 That *the Motion of Comets depends upon the Law of Gravity*, is alſo deduc'd from Obſervations ; and in reſpect of them, as has been ſaid concerning the Planets, the Sun's Gravity prevails, and by that Gravity they deflect from a rectilinear
*980 Courſe ; * but that the Curvature of their Way
226 depends upon the ſame Gravity, follows from this ; That a Body by that Gravity, will deſcribe an Ellipſe, or a Parabola, or an Hyper-
* 241 bola ; * which Lines it appears that thoſe Comets
1208 have deſcrib'd, whoſe Trajectories have been determin'd.

1277 *The Satellites of* Jupiter *and* Saturn *are mov'd by*
* 944 *the ſame Laws about their Primaries, as the Prima-*
966 *ries are mov'd about the Sun*; * wherefore the Expli-
974
*1275 cation of thoſe Motions * may be alſo referr'd to them ; for in theſe three Caſes, ſmaller Bodies are revolving at different Diſtances about a much greater Body : namely, Satellites about *Jupiter* and *Saturn*, and Primary Planets about the Sun.

1278 *Whilſt ſecondary Planets are mov'd about a Primary one, it is evident that they may all be mov'd with one common Motion*, whereby the reſpective Motions withwhich they are mov'd in reſpect of each other, will not be diſturb'd, becauſe a Body may at the
* 125 ſame Time be mov'd by different Impreſſions : * The Motion that a Primary Planet has in common with its Satellites, is the Motion of a Primary Planet about the Sun.

1279 Yet *the Motion of the Secondary Planets is diſturb'd by the Action of the Sun*, towards which they are carried ſometimes faſter, and ſometimes ſlower, according to the different Poſition of the Primary ; and they alſo often concur towards the Sun's Center in different Directions. Theſe Irregularities which are very ſmall, cannot be obſerv'd in the Satellites of *Jupiter* and *Saturn*, tho' they be really like thoſe which are obſerv'd in the Motion of the Moon; the leaſt Deviation of this laſt is very ſenſible to us. But that the Irregularities of the Moon exactly follow from the Theory of Gravity, will appear in the next Chapter.

CHAP. XVI.

The Phyſical Explication of the Moon's Motion.

IT is certain that the Moon and Earth having 1280
once a projectile Motion given them, they
can perſevere in their Motion about their common
Center of Gravity: * if they be carried any * 1263
way by a common Impreſſion directed in parallel
Lines, as was ſaid of the Satellites of *Jupiter* and
Saturn, * this Motion will not diſturb the Mo- * 1278
tion about the common Center of Gravity, which
alone will follow that Direction, becauſe in reſpect
of the two Bodies it is at reſt. But the
Bodies are carried by a Motion compounded of
that Impreſſion and of the Motion about the
common Center of Gravity; * that is, they are * 192
whirl'd about that Center as it is carried along,
as before its Motion when it was at reſt. If
every Moment new Impreſſions common to both
the Bodies act upon them, the Way of the Center
of Gravity may be chang'd every Moment,
which Change will be like that which the Bodies
themſelves wou'd undergo, if they had no reſpective
Motion.

Hence we deduce, that if whilſt the Moon and Earth are whirl'd round their common Center of Gravity, they be both projected, the Way of the Center of Gravity, by the Action of the Sun acting upon both Bodies, is the ſame as a Body projected in the ſame manner, wou'd deſcribe about the Sun.

1281 Whence it follows, *that the Moon diſturbs the Motion of the Earth, and that the common Center of Gravity of thoſe Bodies deſcribes that Orbit about the Sun, which we have hitherto ſaid that the Earth deſcrib'd;* becauſe we overlook'd the Action of the
1282 the Moon; but *the Earth deſcribes an irregular Curve.*

1283 *Fig.* 4. *Plate* XXIV.] Let the Sun be at S; and the common Center of Gravity of the Moon Q, and the Earth M, at the Time of the Full Moon be at F: After one whole Lunation, that is, the next Full Moon, let that Center be at A; and let F D A be the Orbit which we call that of the Earth; but in which it is the Center of Gravity abovemention'd that does really move.

If this Lunation be divided into four equal Parts, after the firſt, the Center of Gravity will be at E, the Moon at P, and the Earth at L; after the ſecond part of the Time, at New-Moon, the Center of Gravity will be at D, the Moon at R, and the Earth at I; in the following Quadrature, the Center of Gravity will be at B, the Moon at O, and the Earth at H; laſtly, at Full-Moon the Center of Gravity being at A, the Moon will be at N, the Earth at G: all which follows from the Revolution of the Earth and Moon about their common Center of Gravity, whilſt it is carried in the Orbit about the Sun.

Therefore we ſee the Earth move in the Curve M L I H G, which is twice inflected in each Lunation; which Curve alſo does not return into it ſelf, becauſe the Inflections in the ſeveral Revolutions about the Sun do not coincide; for 12 Lunations, and a third part of another, are perform'd every Year.

1284 *This Irregularity of the Motion of the Earth*, which is deduc'd from the Laws of Nature, *is too ſmall to become ſenſible in Aſtronomical Obſervations*; wherefore we may without any Error ſay, that the Center of the Earth it ſelf deſcribes the Orbit F DA; for M F, or D I, the greateſt Diſtance of the Earth from that Orbit, is about the 40th part of the Diſtance I R, which Diſtance itſelf is not the 300th part of the Diſtance F S.

1285 *In explaining what relates to the Moon, we alſo neglect the Conſideration of the Motion of the Earth about the common Center of Gravity abovemention'd, but we ſuppoſe it to revolve at the Diſtance of 60 Semidiameters, from the Center of the Earth*; becauſe, as we have before demonſtrated, * ſuch is the Distance at which in its periodical Time, it cou'd revolve about the Earth at reſt, or carried along in an Orbit in which it ſhou'd not be diſturb'd by the Moon's Action. By this Method, the Moon's Irregularities will be much more eaſily diſcover'd; for they are the ſame; as is evident, whether the Moon moves about the common Center of Gravity of the Moon and Earth, or about the Center of the Earth itſelf.

*1253

1286 *Plate* XXV. *Fig.* 1.] Let S be the Sun; T the Earth; and the Orbit of the Moon A LB *l*; and laſt of all, let the Moon be at A in the Quadrature; it tends towards the Sun in the Direction A S, in the ſame manner, and with the ſame Force that the Earth is carried towards S along T S, becauſe the Diſtances A S and T S are equal: This Force may be repreſented by T S or A S,

whereby

whereby the Moon endeavours to deſcend along A S, and be reſolv'd into two Forces, by drawing the Parallelogram A D S T; ſo that the Moon will endeavour to move in the Directions A D and A T, by Forces repreſented by thoſe * 192 Lines. *

By the Force which acts along A D, the Moon is carried with the ſame Celerity and the ſame Way as the Earth; by reaſon of the equal and parallel Lines T S and A D; wherefore by this Motion, the Relation between the Moon and Earth is not chang'd; but the Force along A T 1287 conſpires with *the Gravity of the Moon towards the Earth,* and this Gravity *is encreaſed by the Action of the Sun, when the Moon is in the Quadratures: and it is an Augmentation or Addition to the Gravity of the Earth towards the Sun, as* A T *the Moon's Diſtance from the Earth is to* T S, *the Earth's Diſtance from the Sun.*

T S *the Earth's Diſtance from the Sun remaining the ſame, the* abovemention'd *Addition of Gravity encreaſes, and diminiſhes in the Ratio of the Line* A T, *the Diſtance of the Moon from the Earth.*

But this Diſtance of the Moon from the Earth A T, if it remains the ſame, and T S be encreaſed, then A T will be leſs in reſpect of A S; therefore, tho' there ſhou'd be no change in the Force, whereby the Earth and Moon fall towards the Sun, the Addition will be leſs, and ſo much leſs as T S is greater, that is, it will be inverſly as TS; but the Force of Gravity does not remain the ſame, when T S is increaſed, but is diminiſh'd; wherefore alſo in that reſpect, the abovemention'd Addition is diminiſh'd, and in the ſame Ratio with that Force of Gravity; therefore it is in the inverſe Ratio of the Square of the * 1208 Diſtance T S; * if this Diminution be added to that abovemention'd, we ſee that *the Addition* of which we ſpeak, *follows the inverſe Ratio of the Cube of the Diſtance of the Earth from the Sun.* 1289

1290 *The Diſtance of the Earth from the Sun remaining the ſame, the Gravity of the Moon towards the Earth decreaſes more ſlowly in the Quadratures, than according to the inverſe Ratio of the Square of the Diſtance from the Center of the Earth*; for if the Addition in that caſe ſhou'd follow the inverſe Ratio of the Square of the Diſtance, as the Gravity from the Action of the Earth does, *this Ratio wou'd not be diſturb'd; but the Addition encreaſes when the Gravity itſelf is diminiſh'd; wherefore the Addition, when the Diſtance is increaſed, is always greater than is required, and conſequently the Diminution the leſs.

* 1208

1291 This Addition is determin'd *in the mean Diſtances of the Moon from the Earth, and of the Earth from the Sun*: Let A T and T S be theſe mean Diſtances; *the Addition* required to the Gravity of the Earth towards the Sun, is as A T to T S*; the Gravity of the Earth towards the Sun, *is to the Gravity of the Moon towards the Earth* (becauſe theſe Bodies are retain'd by theſe Gravities in their Orbits) directly as T S to T A, and *inverſly as the Squares of the periodical Times of the Earth about the Sun, and of the Moon about the Earth*: * Therefore the Addition requir'd to the Gravity of the Moon towards the Earth, is in a Ratio compounded of theſe Ratio's; *that is*, the abovemention'd inverſe Ratio of the periodical Times of the Earth and Moon, the other Ratio's deſtroying one another. Theſe Times are given, and their Squares are inverſly *as* 1 *to* 178,73.

* 1287

* 237 1236

1292 Now if the Moon be at L, [*Plate* XXV. *Fig.* 1.] in which Situation the Sun attracts the Moon and Earth in the ſame Line, but not equally; the Moon it draws with a greater Force, becauſe it is leſs diſtant from it: The Difference of

thoſe

thoſe Forces is the Force by which the Moon is drawn back from the Earth, and by which the Gravity of the Moon towards the Earth is diminiſh'd.

The Forces, whereby the Moon at L, and
the Earth at T, tend towards the Sun, are to
one another as the Squares of the Lines S T and
*1208 S L *; and the Difference of the Forces, that is,
the diſturbing Force, is to the Force by which
the Earth deſcends towards the Sun, as the
Difference of thoſe Squares to the Square of the
Line L S; that is, nearly as double L T to L S
or T S; for theſe Lines do but very little differ
1293 from one another; and *the Difference of the Squares,
whoſe Roots differ but little, is keeping the Proportion
double that which is between the Roots.*

If therefore T S, as before, repreſents the Force
whereby the Earth deſcends towards the Sun,
L *l* will repreſent the diſturbing Force and
diminiſhing Gravity, when A T repreſents the
*1286 diſturbing Force in the Quadratures. * Let the
1294 Moon be at *l*; it is again (together with the
Earth) attracted by the Sun in the ſame Line;
but the Earth, becauſe leſs diſtant, moves
*1208 more ſwiftly towards the Sun; * ſo that there
is a Force which ſeparates the Earth from the
Moon, namely, the Difference of the Forces
which attract the Moon and the Earth; which
Force always acts contrary to the Gravity of the
Moon towards the Earth, and diminiſhes it, in
the ſame manner as has been demonſtrated from
the greater Gravity of the Moon towards the
Sun, ſuppoſing it at L. At *l* alſo the
ſeparating Force ſcarce differs from the ſeparating
Force at L; for this Force, as we have ſhewn,
is proportional to the Difference of the Squares
of the Lines T S and L S; and that (as appears
by ſuch another Demonſtration) proportional to
the

the Difference of the Squares of the Lines *l* S, and T S; which Differences, by reaſon that L *l* is very ſmall in reſpect of T S, ſcarce differ among themſelves; ſo that the Force, which diminiſhes the Moon's Gravity at *l*, is aſo repreſented by L *l*.

Yet *the Diſturbing Force is ſomething greater at the Conjunction* L *than at the Oppoſition l*; for ſuppoſing the Differences between the Roots to be equal, the Squares keeping the Proportion, will differ ſo much the more, the leſs they are; and ſo keeping the Proportion, the Forces differ more at L and T, than at T and *l*, which alſo are leſs. * 1295 *1208

From this we conclude, that *the Force which diminiſhes the Gravity of the Moon in the Syzygies, is double that which encreaſes it in the Quadratures; namely, as* L *l to* A T. Wherefore in the Syzygies, the Gravity of the Moon from the Action of the Sun is diminiſh'd by a Part, which is to the whole Gravity, *as* 1 *to* 89,36.; for in the Quadratures, the Addition of Gravity is to the Gravity, as 1 to 178,73. * 1296 *1291

In the Syzygies, the diſturbing Force follows the ſame Proportion with half added to it; that is, with the diſturbing Force in the Quadratures *; *it is* therefore *directly as the Diſtance of the Moon from the Earth,* * *and inverſly as the Cube of the Diſtance of the Earth from the Sun.* * 1297 *1296 *1288 *1289

At the Syzygies the Gravity of the Moon towards the Earth, receding from its Center, is more diminiſh'd, than according to the inverſe Ratio of the Square of the Diſtance, from that Center; for they wou'd be diminiſh'd in that Ratio, if the Force to be taken away follow'd the ſame Ratio; but on the contrary, as it encreaſes when the Diſtance becomes greater, * the Diminution is always greater than in that Ratio. 1298 *1297

1299 *Plate* XXV. *Fig.* 1.] Laſtly, let the Moon be at F, in any intermediate Place between the Syzygy and Quadrature, it is drawn towards the Sun along F S; by which ſince it is leſs diſtant than the Earth T, it is attracted with more Force than the Earth: Let the Force, with which the Moon tends to the Sun, be to the Force, with which the Earth is carried towards it, as F M to T S, which alſo before has been made uſe of to expreſs the ſame Gravity of the Earth. Draw the Parallelogram F H M I, whoſe Diagonal is F M, and whoſe Side F H is parallel and equal to the Line T S. The Motion of the Moon towards the Sun is reſolved into two Motions, one along F H, the other along F I, and theſe Lines denote the Forces whereby the Moon endeavours * 192 to move along them. * The Motion along F H is common to the Moon and the Earth, which with an equal Force, and in a Line parallel to it, does alſo tend to the Sun; ſo that by this Motion of the Moon, the Situation of it, in reſpect of the Earth, will not be chang'd, and the diſturbing Force will be only the Motion along F I.

By reaſon of the immenſe Diſtance of the Sun, the Part M S of the Line M F, is ſmall in reſpect of the whole, and the Angle F S T, where it is the greateſt, as A S T, is hardly more than the 6th part of a Degree; whence it follows, that the Lines M I and S N are very near one another, and that the Points I and N are ſcarce ſenſibly diſtant, and may without any ſenſible Error be confounded together; which Error, notwithſtanding how little ſoever it need be regarded, in conſideration of one whole Revolution, is compenſated by a contrary Error when the Moon is at E. Therefore the diſturbing Force is expreſſed by F N.

Fig 1.

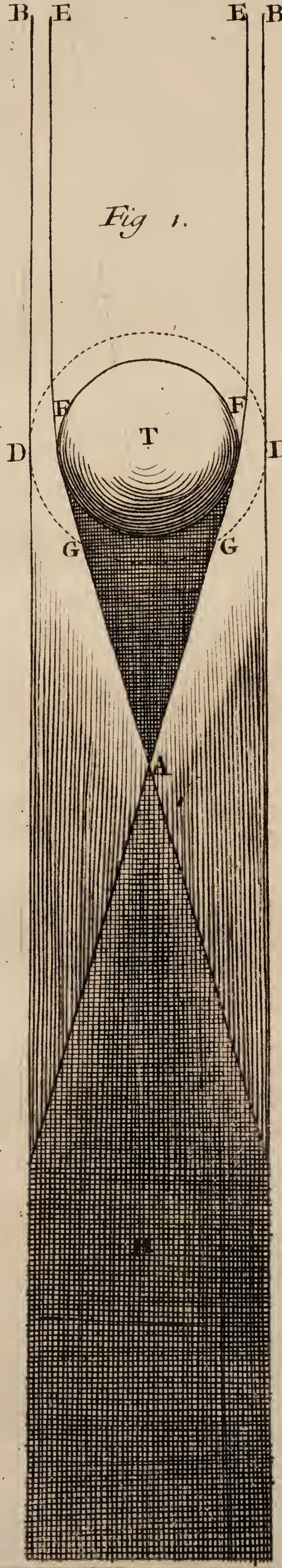

B
E
E
B
F
F
T
D
D
G
G
A

Fig. 2.

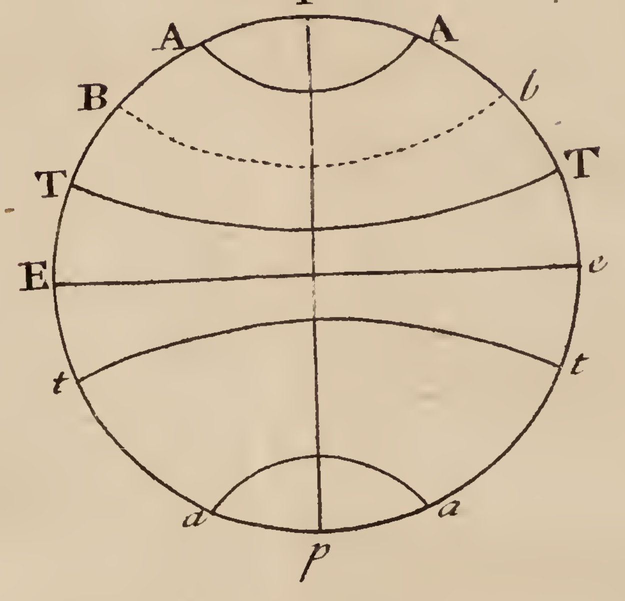

P
A
A
B
b
T
T
E
e
t
t
a
a
p

Fig. 3.

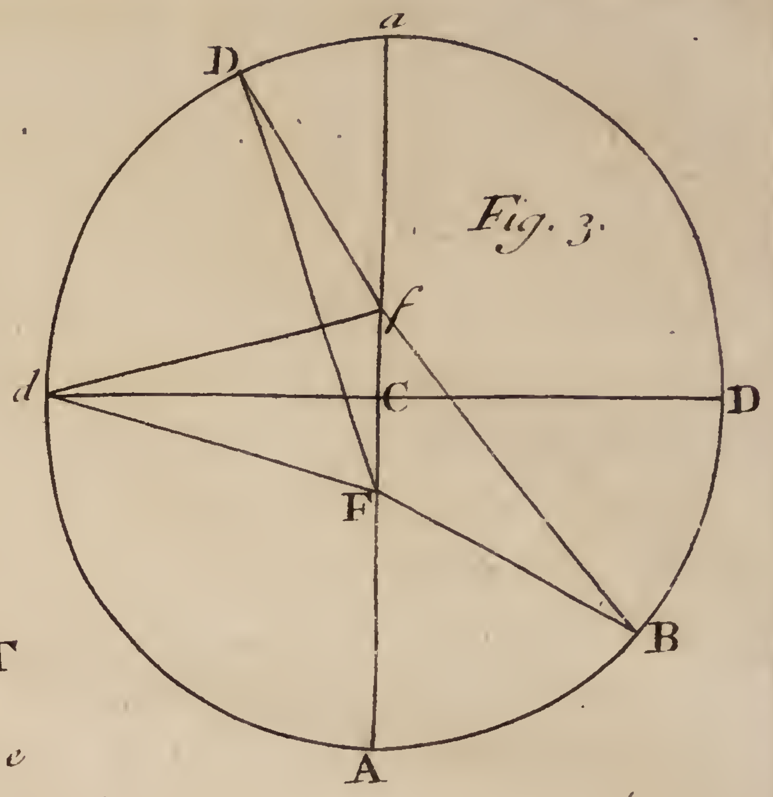
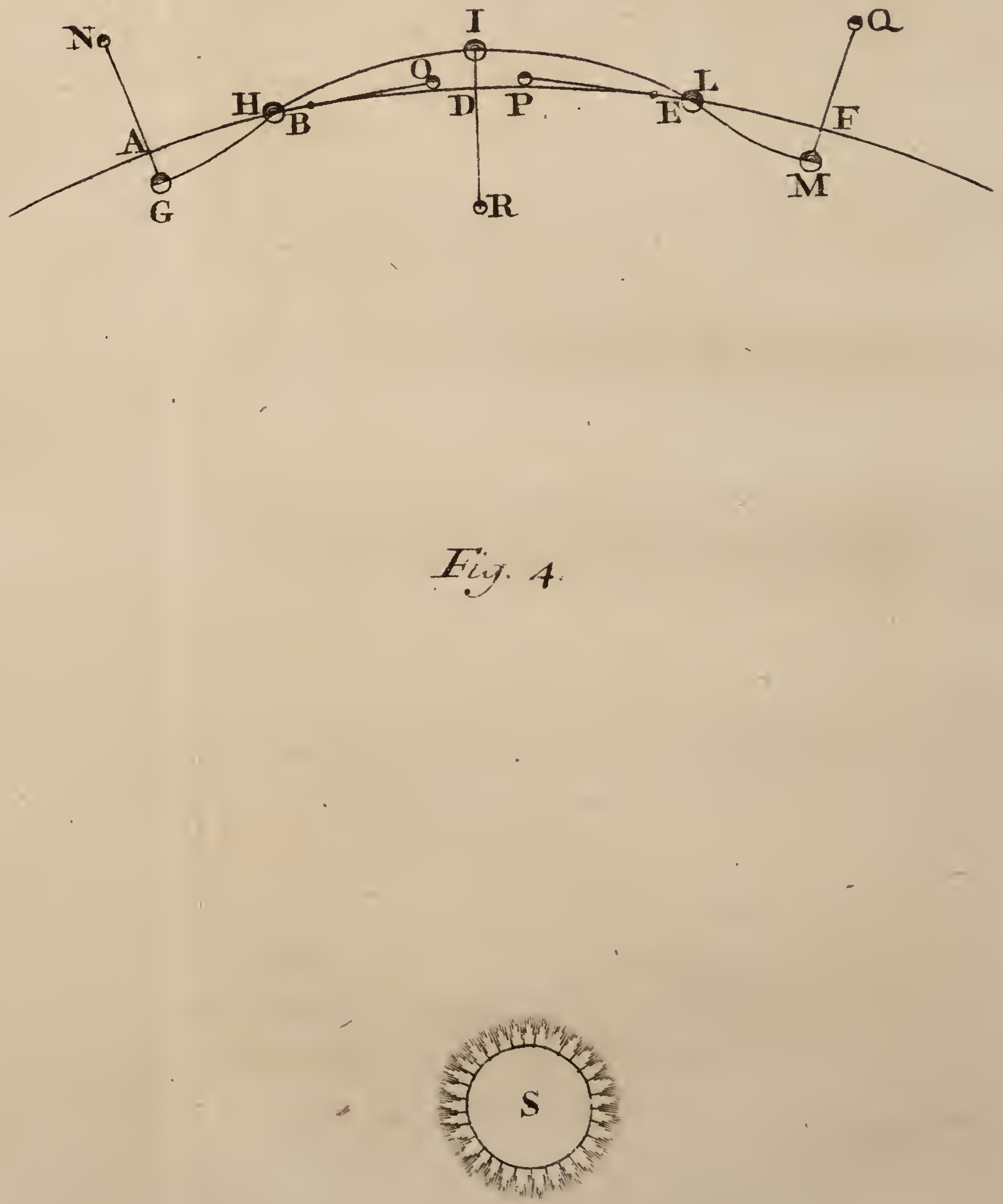


Fig. 4.


N
I
Q
O
H
B
D
P
E
L
F
A
G
R
M
S

It is to be obſerved, when only the Part E F of the Line E S is conſider'd, that it is to be look'd upon as parallel to the Line L *l*, becauſe of the ſmall Angle which theſe Lines make. 1300

From the Point N, draw N Q perpendicular to the Line F T, continued if need be, in which the Moon gravitates towards the Earth; and let the Rectangular Parallelogram F P N Q be drawn; let us conceive the Force along F N reſolv'd into two others, acting in the Directions F Q and F P, and repreſented by theſe Lines: * By the Force along F Q, the Force of Gravity is diminiſh'd, in the caſe repreſented by this Figure; but it is encreaſed when the Point Q falls between F and T; but by the Force along F P, the Moon in its Orbit is drawn towards the next Syzygy L, and the Motion of the Moon is accelerated or retarded, according as this Force conſpires with or acts contrary to the Moon's Motion. 1301

* 192.

Near a Syzygy, the Gravity of the Moon is diminiſh'd, and the Line F Q, which follows the Proportion of this Diminution, grows leſs, receding from the Syzygy till it vaniſhes, at the Diſtance of about 54 Deg. 44 Min. from it; at a greater Diſtance of the Moon, from the Syzygy, Q falls in between F and T; and the Gravity of the Moon towards the Earth is encreas'd by the Sun's Action. The Force along F P vaniſhes in the Syzygy L, receding from it it encreaſes quite to the Octant, which is the middle Point between the Syzygy and the Quadrature; and then it diminiſhes again till it vaniſhes quite at B.

1302 Between B and *l*, or *l* and A, the diſturbing Motions are determin'd in the ſame manner, as in A L B, the oppoſite inferior Part of the Orbit; at E and F, the Diminution of Gravity is equal, and in that Poſition it is drawn in the Orbit with an equal Force towards the Syzygy *l*, with that with which at F it is impell'd towards the Syzygy L.

1303 Hence it follows, *that in the Motion of the Moon from the Syzygy to the Quadrature*, between L and B, as alſo between *l* and A; *the Gravity of the Moon towards the Earth is continually encreas'd, and*
1304 *the Moon is continually retarded in its Motion.* But *in the Motion from the Quadrature to the Syzygy*, between B and *l*, as alſo between A and L, *every Moment the Moon's Gravity is diminiſh'd, and its Motion in its Orbit is accelerated.*

You may determine the Forces upon which theſe Effects depend, by comparing them with the known Force, whereby Gravity is encreas'd in the
1291 Quadratures, and which is repreſented by the Moon's Diſtance from the Center of the Earth.

1305 The Lines M I, H F, S T, are equal by Conſtruction; therefore when the Points I and N are confounded, M N is equal to S T, and M S is equal to N T. The Lines M F and S T repreſent the Forces, whereby the Moon at F and the Earth at T are carried towards the Sun S; therefore they are as the Square of the Line
1208 T S to the Square of the Line F S; wherefore, as F G is the Difference of thoſe Lines, F M and T S differ from one another double the Line
1293 G F, and adding G F to the Line F M, the Difference between G M and T S, that is, M S will be triple the Line F G; and therefore this is alſo the Quantity of the Line N T: Now as
1300 F E is double F G; therefore N T will be to F E as Three to Two.

Let F T be continued, if need be, and from E draw E V perpendicular to it; the Triangles E V F and N Q T, which are rectangular, will be ſimilar, by reaſon of the alternate Angles

V F E

V F E and Q T N :* Therefore N T is to F E, *1300 that is, Three is to Two, as N Q, equal to F P, is to E V; which therefore is proportional to two third Parts of the Force, which is expreſſed by F P; but E V is the Sine of the Angle E T V at the Center, which is double the Angle E F V at the Circumference, equal to the Angle F T L, which is the Diſtance of the Moon from the Syzygy. Therefore, *as the Radius* 1306 T A, or T E, *is to a Sine and an half of double the Diſtance of the Moon from the Syzygy*, namely F P, *ſo the Addition of Gravity in the Quadratures* (which is expreſs'd by the Radius T A) *is to the Force which accelerates or retards the Moon in its Orbit.*

The Computation of this Diminution of Gravity, and of its Encreaſe at a leſs Diſtance from the Quadratures, is deduced from the ſame Principles.

This Diminution is repreſented by the Line F Q, which is equal to Q T, *minus* the Radius; but from the Conſideration of the Triangles above-mention'd, V F taken once and a half is equal to Q T; therefore V T and an half, with half the Radius added to it, expreſſes the requir'd Diminution of Gravity; and *the Radius*, 1307 *is to the Sum or Difference of once and a half the Co-ſine of double the Diſtance of the Moon from the Syzygy and half the Radius: As the Addition of Gravity in the Quadratures, to the Diminution or Encreaſe of Gravity in that Situation of the Moon, concerning which the Computation is made.*

We make uſe of the Difference of the Co-ſine from half the Radius, when the Angle, whoſe the Co-ſine is, is greater than a right Angle; becauſe in that Caſe we make uſe of the Co-ſine of the Complement of the Angle to two right Angles: When in this ſame Caſe the Co-ſine and a half, which we make uſe of, is greater than half the Radius, the Quantity found is to be added; that is, encreaſes the Gravity, which obtains every where between the Quadrature, and 35 Deg. 16 Min. from it.

1308 *Theſe Forces, whatever is the Figure of the Moon's Orbit, are exactly determin'd*; for they are compar'd with the Addition of Gravity in the Quadratures, ſuppoſing the Moon in the Quadrature to be at the ſame Diſtance from the Earth, at which it really is in the Place which is conſider'd; but this Addition is diſcover'd in every Caſe.* *1291

1288, 1289, Tho' it be foreign to the Purpoſe of this Work, to give a Computation of the Moon's Motion, I thought it neceſſary to explain in a few Words, what is the Method whereby to diſcover the Forces that govern the Moon; becauſe the more exactly we know the Forces, the more eaſily we ſhall conceive their general Effect.

Now to examine the Moon's Motion, we muſt ſingly conſider its ſeveral Irregularities; which to do without Confuſion, we muſt remove ſeveral Irregularities, and conceive the Moon as moving in a Circle about the Earth, in which Curve it is plain, that it can be retain'd by Gravity.* This Motion is diſturb'd by the Action of the Sun, and *the Orbit is more convex in the Quadratures than in the Syzygies.* The Convexity of a Curve, which a Body deſcribes by a central Force, is ſo much the greater, as the central Force does more ſtrongly every Moment turn the Body out of the Way; it is alſo the greater, the more ſlowly the Body moves; becauſe the central Force acting the longer, has a greater Effect in inflecting the Way of the Body. From contrary Cauſes the Convexity of the Curve is diminiſh'd. Both concur in increaſing the

* 241, 1208

1309

the Convexity of the Orbit in the Quadratures,* *1303
and diminiſhing it in the Syzygies.* *1304

From this it follows, that the circular Figure 1310
of the Moon's Orbit is changed into an Oval,
whoſe greater Axis goes thro' the Quadratures;
ſo that the more convex Parts are in the Quadratures.
Wherefore *the Moon is leſs diſtant from
the Earth at the Syzygies, and more at the Quadratures*;
and it is no Wonder that the Moon comes
towards the Earth, when its Gravity is diminiſh'd;
becauſe the Acceſs is not the immediate
Effect of this Diminution, but of the Inflexion
of the Orbit towards the Quadratures.

The Motion of the Moon, taking away the
Action of the Sun, is not in a Circle, but in an
Ellipſe, one of whoſe Foci coincides with the
Center of the Earth;* for the Orbit of the *967,
Moon is Excentric, and it is retain'd in it by 241,
the Force of Gravity. 1208

Therefore what has been demonſtrated cannot
be exactly applied to the Moon's Motion;
for as the Forces which generate the Deviations
explain'd, do really act upon the Moon, the Ellipſe,
which the Moon would deſcribe if the Sun
was taken away, is chang'd, and *cæteris paribus*, 1311
the Propoſitions of N° 1309, 1310. *may be applied
to the Moon's Motion.*

In the Quadratures and Syzygies, the diſturbing 1312
Force acts in the ſame Line as the Force of
Gravity towards the Earth;* therefore the Force *1286
which continually acts upon the Moon, and retains 1292,
it in its Orbit, is directed towards the 1294
Center of the Earth, and *the Moon deſcribes Area's
by Lines drawn to the Center of the Earth, proportional
to the Times.** *215

Plate XXV. *Fig.* 1.] *In other Points of the Orbit*, 1313
as F, beſides the Force which acts in the
Line F T, there is alſo another, whoſe Direction

1301 ction is perpendicular to F T, which is here
repreſented by F P: The Direction of the Force
compounded of both is directed ſomething ſide-
wiſe to the Line F T, and does not tend to the
190 Center of the Earth; wherefore *the Area's, by
Lines drawn to the Center of the Earth, are not ex-*
*226 *actly proportional to the Times.** In the Octants,
F P is the greateſt of all; and the Force which
is repreſented by that Line, is to the Gravity of
the Moon towards the Earth, in that Point, in
the Mean Diſtances of the Sun and Moon, as 1
1306 to 119,49. Wherefore the Direction of the
1307 Force, compounded of the Actions of the Sun
and Earth upon the Moon, makes an Angle of
above half a Degree with the Line F T.

The Motion of the Moon is ſubject to ſeve-
ral other Irregularities; ſo that it deſcribes a
Curve wholly irregular; which *Aſtronomers*, in
order to ſubject it to the moſt exact Computa-
1314 tions that can be made, do *reduce to an Ellipſe,
which they conceive to be agitated by various Motions,
and alſo to be changeable, leaſt the Moon ſhould go out
of it.*

In reſpect to central Forces we have obſerv'd,
that a Body does not deſcribe an Ellipſe, if the
central Force by which it is retain'd in its Or-
bit, decreaſes in any other Ratio than the In-
verſe Ratio of the Square of the Diſtance; but
that the Curve may be often reduc'd to a move-
243 able Ellipſe: Concerning which it is to be ob-
1315 ſerv'd, that *the Ellipſe*, in that Motion, *turns
about one of its Foci, and the Motion of the Ellipſe is
directed the ſame Way as the Motion of the Body in*
1316 *it, when the central Force decreaſes faſter than in the
Inverſe Ratio of the Square of the Diſtance.* But *if
the central Force decreaſes ſlower, as you recede from
the Center, the Ellipſe is carried the contrary Way*;
as theſe Things may be demonſtrated Mathe-
matically.

Hence it follows, that the Orbit of the Moon cannot be referr'd to an Elliptical Orbit, unleſs you ſuppoſe it agitated by four Motions every Revolution; that is, unleſs the Line of the Apſides, which goes thro' the Center of the Earth, goes forwards twice, and backwards twice.

The Apſides of the Moon go forward when the 1317
*Moon is in the Syzygies,** or rather whilſt the *1315
Moon moves between the Points, which are 1298
54 Deg. 44 Min. diſtant from them.* *In the* *1307
Quadratures, and between the Points diſtant
from them 35 Deg. 16 Min. *the Apſides go back-* 1318
wards, that is, move in *Antecedentia.** *1316

The Forces upon which *the Progreſs* and Re- 1290
greſs *of the Apſides* depend, are the Forces which 1307
diſturb the Motion of the Moon, which have 1319
been before explain'd; therefore, ſince the diſturbing Force in the Syzygies, is double the diſturbing Force in the Quadratures;* the Pro- *1296
greſs, *conſidering one entire Revolution of the Moon, exceeds the Regreſs, cæteris paribus.*

In a Circle whoſe Center is in the Center of the Forces, the Diminution of the Force, in receding from the Center, produces no Effect; becauſe in ſuch a Line the Body does not recede from the Center; therefore the Effect of this Diminution is ſo much the greater, as the Curve deſcrib'd by the Body differs more from ſuch a Circle.

In an Elliptic Orbit, one of whoſe Foci co- 1320
incides with the Center of the Forces, the Curvature in *the Apſides* differs moſt of all from ſuch a Circle, and *the Effect of the Diminution of the Force, in receding from the Center of the Forces, is the greateſt of all. If this Orbit is but a little Ex-* 1321
centric at the Ends of the leſſer Axis, the Ellipſe differs very little from the Circle above-mention'd, and *the Effect of the Diminution is the leaſt of all.*

The

1322 The *Progreſs and Regreſs of the Apſides* depend
upon the Proportion, according to which the
Force of Gravity decreaſes, receding from the
1315 Center of the Earth; it *is* therefore *the Effect*
1316 *of the Diminution of the Central Force.*

1323 *Plate* XXV. *Fig.* 2.] This Motion of the
Apſides, which we have explain'd, undergoes
ſeveral Changes; *the Apſides go forward faſteſt of*
*1317 *all in a Revolution of the Moon, ſuppoſing the Line*
1322 1320 *of the Apſides in the Nodes;* * *and in that very Caſe*
*1318 *they go back the ſloweſt of all in the ſame Revolution,**
1321 becauſe, by reaſon of the ſmall Excentricity of the
1322 Moon, the Quadratures are but very little diſtant
from the Ends of the leſſer Axis of the Orbit.

1324 *Suppoſing the Line of the Apſides to be in the Qua-*
*1317 *dratures, the Apſides are carried in* Conſequentia,
1322 *the leaſt of all in the Syzygies;** *but they return the*
1321 *1318 *ſwifteſt in the Quadratures;** *and, in this Caſe, in*
1322 *one entire Revolution of the Moon, the Regreſs ex-*
1320 *ceeds the Progreſs.*

1325 Whilſt the Earth is carried along in its Or-
bit, the Line of the Apſides does ſucceſſively
go thro' all Situations in reſpect of the Sun;
wherefore, *conſidering a great many Revolutions of*
*1319 *the Moon taken together, the Apſides go forwards;**
and it is plain from Obſervations, that in the
Space of about eight Years, the Line of the Ap-
ſides performs one entire Revolution.

We have alſo ſaid that the Excentricity of the Orbit is not conſtant.

1326 *The Excentricity of a Body is increas'd, if the central Force*, the Diminution being continued, *decreaſes faſter than before*, whilſt the Body is carried from the lower to the upper Apſis; for then it is every Moment leſs attracted, than if the Force did not decreaſe; and therefore it recedes the more. The Excentricity of the Orbit is alſo thereby encreas'd, in the ſame Caſe, in

the Motion from the upper to the lower Apſis;
becauſe in this Caſe, coming towards the Cen-
ter, the Force encreaſes ſo much the faſter, as
the Body deſcends more towards the Center;
ſo that in each Caſe, the Difference between
the greateſt and leaſt Diſtance from the Center
of the Forces, may become greater, and the
Excentricity be thereby encreas'd. By the ſame 1327
Reaſoning it appears, that *the Excentricity is di-*
miniſh'd, when the central Force is increas'd, in the
Motion of the Body from the lower to the up-
per Apſis; and likewiſe when that Force is di-
miniſh'd in the Motion from the upper Apſis to
the lower; that is, when *it decreaſes more ſlowly*
than before, in receding from the Center.

Applying this to the Moon's Motion, it ap- 1328
pears, that *the Excentricity of the Orbit, every Re-*
volution, undergoes various Changes. That it is the 1329
greateſt of all, when the Line of the Apſides is in the
Syzygies; becauſe the Forces in the Apſides be-
ing compar'd, do decreaſe faſter than in an in-
verſe Ratio of the Square of the Diſtance,* *1298
whence this Addition follows,* which prevails *1326
in this Poſition:* But *the Orbit is the leaſt Ex-* *1320
centric of all, when the Line of the Apſides is in the
Quadratures, the Diminution of the Excentricity
prevailing.* *1290

We have ſaid that the Moon moves in a Plane 1327 1321
inclin'd to the Plane of the Ecliptic; that the
Line of the Nodes is carried round in *Anteceden-*
tia;* and that the Inclination of the Orbit is *970
not conſtant;* theſe Effects are deduc'd from the *969
Action of the Sun and the Moon.

By reaſon of the ſmall Inclination of the Moon's Orbit, the Forces which we have hitherto conſider'd acting in the Plane of the Ecliptic, not regarding the Inclination of the Orbit, may (without any ſenſible Error) be referr'd to the Plane

of the Orbit; and the Moon in it is ſubject to
1330 the Motions before explain'd: But *there is a Force
which removes the Moon from the Plane of the Or-
1314 bit;* ſo that we muſt conceive that Plane to be
agitated, otherwiſe the Moon wou'd go out of
the Orbit.

1331 *Plate* XXV. *Fig.* 1.] Let the Moon be at F;
if we attend to what has been ſaid above con-
1299 cerning the Action of the Sun, it is plain, that
the Plane of the Parallelogram F H M I goes
thro' the Line T S, which joins the Centers of
the Earth and Sun; and therefore it is in the
Plane of the Ecliptic; ſo that the Point N, to
which is directed the Force F N, diſturbing on
account of the Action of the Sun, is in that
Plane.

1332 *Plate* XXV. *Fig.* 4.] Let this ſame Force be
repreſented by F I; at F let F R be rais'd per-
pendicular to the Plane of the Orbit; and ima-
gine the Parallelogram F R I *i*, whoſe Side F *i*
is in the Plane of the Orbit, and whoſe Diago-
nal is F I; the diſturbing Force along F I is re-
ſolv'd into two, in the Directions F R and F *i*
192 which theſe Lines repreſent, and of which this
laſt acts in the Plane of the Orbit: So that we
muſt refer to this what relates to the diſturbing
Force, of which we have treated in N° 1299;
for the Lines F *i* and F I ſcarce differ, and the
Plane of the Parallelogram F R I *i* is perpendi-
cular to the Plane of the Moon's Orbit.

1333 The Line F R muſt be determin'd, which re-
preſents the Force that acts perpendicular to the
Plane of the Orbit, and removes the Moon
from that Plane; now the Relation of the Line
F R or I *i* to the Radius E T, is the Ratio of
the diſturbing Force, which is ſpoken of here,
1286 to the Encreaſe of Gravity in the Quadratures.

1334 In the Caſe of this Figure, in which the Line of Nodes N *n* is in the Quadratures, we find out F R; becauſe **I T** (which is N T of *Fig.* 1.) is given,* and becauſe **I T** is to I *i*, or to F R, *1305 as the Radius to the Sine of the Inclination of the Orbit.

1335 But in every Caſe the Force muſt be determin'd, which drives the Moon out of the Plane; let us therefore ſuppoſe the Line of Nodes carried to the Situation M*m*, whereby, every thing elſe remaining as before, I *i* is chang'd. To M *m* continued, if need be, let *i* X and I X be drawn perpendicular, which make an Angle equal to the Inclination of the Plane of the Orbit.

1336 The Ratio between E T and I *i*; that is, *the Ratio between the Addition of Gravity in the Quadratures, and the Force,* which we ſeek, *which removes the Moon out of its Orbit,* is compounded of the Ratio's of the Line E T to T I, of the Line T I to I X, and laſtly of the Line I X to I *i*. The firſt is the Ratio between the Radius and three times the Sine of the Diſtance of the Moon from the Quadrature;* the ſecond is the *1305 Ratio of the Radius to the Sine of the Angle I T X, that is of the Diſtance of the Node from the Syzygy; *Laſtly,* The third is the Ratio of the Radius to the Sine of the Inclination of the Orbit: And the Ratio compounded of theſe, *is the Ratio of the Cube of the Radius to three times the Product of the Sines of the Diſtances of the Moon from the Quadrature, and of the Node from the Syzygy, as alſo of the Inclination of the Plane.* To this Force alſo is to be referr'd N° 1308.

1337 *This Force vaniſhes in the Quadratures,* becauſe the Point I coincides with the Point T, which is the Center of the Earth, and the Line I *i* vaniſhes; the Lines F I and F *i* concurring in the Plane of the Orbit, which alſo follows from the Computation above-mention'd;* the Sine of *1136 the Diſtance of the Moon from the Quadrature vaniſhing, and conſequently, the whole Product which is multiplied by that Sine.

1338 That ſame Product vaniſhes alſo, and with it *the Force* which it repreſents, when the Sine of the Diſtance of the Node from the Syzygy *vaniſhes*, that is, *ſuppoſing the Line of Nodes in the Syzygies*: It is alſo deduc'd from this, that the Line of Nodes N *n* (*Plate* XXV. *Fig.* 5.) continued goes thro' the Sun, wherefore the Sun is in the Plane of the Orbit itſelf, and therefore cannot draw the Moon but in that Plane.

1339 *The Force* alſo, *which we examine, is increas'd as the Moon advances towards the Syzygy, and as the Node recedes from it,** *1336

1340 *Plate* XXV. *Fig.* 6.] Let P*p* be the Plane of the Ecliptic, PA the Orbit of the Moon; when the Moon is come to A, that is, is receded a little from the Node, it is remov'd out of the Plane of the Orbit, and in the ſecond Moment it is not carried along AB (the Continuation of the Orbit PA) but along A*b*; becauſe it comes towards the Plane of the Ecliptic along B*b*; therefore it is mov'd as if it came from a more

1341 diſtant Node *p*. Whence it appears, that *the Nodes go backward, whilſt the Moon moves in its Orbit*, as long as it recedes from the Node: The Nodes alſo go back whilſt the Moon is going to the oppoſite Node; becauſe as the Moon is continually driven out of its Orbit towards the Plane of the Ecliptic, it is continually directed to a Point leſs diſtant, and comes ſooner to the Node, than if not being agitated by ſuch a Motion, it had continued in Motion with the ſame Celerity.

1342 *Conſidering one entire Revolution of the Moon*, cæteris paribus, *the Nodes move in* Antecedentia *ſwifteſt of all, when the Moon is in the Syzygies,** *1339 *then ſlower and ſlower, till they are at reſt, when the Moon is in the Quadratures.** *1337

Whilſt the Earth is carried round the Sun (even when we don't attend to the above-mention'd Motion of the Nodes) *the Line of Nodes* 1343
does ſucceſſively acquire all poſſible Situations in reſpect of the Sun; and *every Year goes twice thro' the Syzygies, and twice thro' the Quadratures.*

If now *we conſider ſeveral Revolutions of the* 1344
Moon, the Nodes in one whole Revolution go back very faſt, the Nodes being in the Quadratures; then* *1339
*ſlower, till they come to Reſt, when the Line of Nodes is in the Syzygies.** *1338

By the ſame Force with which the Nodes are 1345
mov'd, *the Inclination of the Orbit* is alſo chang'd; it *is encreas'd as the Moon recedes from the Node;* *and diminiſh'd as it comes to the Node.*

Plate XXV. *Fig.* 6.] For the Angle *b p* L 1346
is leſs than the Angle A P L, and for the ſame Cauſe it is continually diminiſh'd, and the Inclination becomes greater; but when the Moon is come to the greateſt Diſtance from the Plane of the Ecliptic, and is going towards the oppoſite Node, the Direction of the Moon is continually inflected towards the Plane of the Ecliptic, and leſs inclin'd to it than if it continu'd in Motion in its Orbit: Let N *p n* be the Plane of the Ecliptic; the Curve N *n* the Orbit of the Moon; by the Force whereby the Moon is continually removed out of it, the Way of the Moon is chang'd, and it goes in the Curve N *p*, which is more inclin'd to N *p n* at N than at *p*; ſo that we muſt conceive the Inclination of the Plane of the Orbit to be twice chang'd,* whilſt the Moon *3114
moves from one Node to the other; therefore this happens four times *in each Revolution of the* 1347
Moon, it is twice diminiſh'd, and twice again encreas'd.

Plate XXV. *Fig.* 4.] *Suppoſing the Nodes* N *n*, 1348
to be *in the Quadratures*, the Forces which *in one Revolution* encreaſe *the Inclination*, and diminiſh it, are equal to one another; for by reaſon of the

equal

equal Diſtance of each Node from the Syzygies,
the Forces that change the Inclination at N D
and *n* E are equal to the Forces in the
* 1336 correſpondent Points in the Arcs D *n* and E N; * by the
former the Inclination is encreas'd, by the latter
* 1345 it is diminiſh'd; * the Diminution of the Angle
of Inclination on account of the firſt is reſtor'd
by the Action of the ſecond, and here it *is not*
* 1343 *chang'd*. In the Motion above-mention'd* of the
Line of Nodes in reſpect of the Sun, which
depends upon the parallel Situation of this Line,
the Node N is carried to the Syzygy E. When
(*for Ex.*) the Line of Nodes is come to the Situation
M *m*, the Moon in its Receſs from the
Nodes goes thro' the Quadratures N *n*, in
which the Force which changes the Inclination
* 1337 vaniſhes,* and near which it is the leaſt of all:*
* 1336 but in coming towards the Nodes, the Moon
is every where diſtant from the Quadratures,
* 1336 and a greater Force acts upon it; * therefore
1349 *conſidering one entire Revolution*, the Increaſe of the
* 1345 Angle of Inclination exceeds its Diminution; *
that is, that Angle is encreas'd, or, which is the
ſame, *the Inclination is diminiſh'd*; which obtains
every where *in the Motion of the Nodes from the
Quadratures to the Syzygies.*

1350 *When the Nodes are come to the Syzygies, the Inclination
1351 of the Plane of the Orbit is the leaſt of all*;
for *in the Motion of the Nodes from the Syzygies to
the Quadratures*, the Plane of the Orbit is continually
more and more inclin'd; for in that Caſe
as the Moon goes to the Node, it paſſes thro'
the Quadratures; in its Receſs from them the
Moon is diſtant from the Quadratures, and *in
one whole Revolution of the Moon*, the Force which
* 1337 encreaſes the Inclination* exceeds that which
* 1345 diminiſhes it; * therefore *the Inclination is
1352 encreas'd*; and *it is the greateſt of all when the Nodes
are in the Quadratures*, where the Diminution of
the

the Angle made by the Plane of the Orbit with
the Plane of the Ecliptick is terminated.* * 1349

All the Errors in the Moon's Motion that we have 1353
explain'd *are ſomething greater in the Conjunction* * 1295
*than in the Oppoſition.**

All the diſturbing Forces are determin'd by diſ- 1354
covering their Relation with the Addition of
Gravity in the Quadratures ;* for which Rea- * 1306
ſon they all undergo the ſame Changes as that 1307
Addition does, that is, they *are inverſly, as the* 1336
*Cube of the Diſtance of the Sun from the Earth,** * 1289
which when it remains the ſame, they are as the Di-
*ſtance of the Moon from the Earth.** *Conſidering* * 1288
all the diſturbing Forces together, the Diminution of 1355
*Gravity prevails ;** which follows immediately * 1296
from the Progreſs of the Apſides ;* for it appears * 970
from thence, that conſidering ſeveral Revolutions 1325
together, the Effect of the Diminution of Gravity * 1317
exceeds the Effect of the Encreaſe of it.* 1318

Therefore *the Motion of the Moon being conſider'd* 1356
in general, the Gravity of the Moon towards the
*Earth is diminiſh'd coming near the Sun ;** therefore * 1355
when it is leſs attracted by the Earth, it recedes 1354
more from it than it would recede if there was
no ſuch Diminution of Gravity ; therefore in
that Caſe the Moon's Diſtance is encreas'd, as 1357
alſo *the Periodical Time ;** and that Time *is the* * 224
greateſt, as alſo the Diſtance of the Moon (cæteris pari- *
*bus) the greateſt, when the Earth is in the Perihelion,** 1354
becauſe then it is leaſt diſtant from the Sun.

CHAP. XVII.

Concerning the Figures of the Planets.

IF we conſider the Figures of the Planets, we ſhall find that they have ſuch Figures, which follow from theſe very Laws by which

the Syſtem is govern'd; which is very agreeable to that admirable Order which we obſerve every where, that no Forces act upon the Planets to
1358 deſtroy them; that is, that *the Figure of a Planet, whether it be a Primary or Secondary Planet, is ſuch as it would acquire, if it wholly conſiſted of fluid Matter*; which agrees with the Phænomena.

1359 Whence it follows, that *all the Primary and Secondary Planets are Spherical*; for they conſiſt of
*1206 a Matter whoſe Particles gravitate towards one
1207 another;* from which mutual Attraction a Spherical Figure is generated in the ſame Manner as a Drop becomes round from another Sort of At-
34 traction of the Parts.

1360 *This Spherical Figure of the Planets is not chang'd from their Motion round the Sun, or from the Motion of the Secondary Planets about their Primary ones*; becauſe all the Particles are carried by the ſame Motion: But this Figure undergoes ſome Change by the Motion round the Axis, and ſo much the greater as this Motion is ſwifter.

1361 *Plate* XXV. *Fig.* 7.] Let PP be the Axis of *a Planet*; E *e* the Diameter of the Æquator, perpendicular to the Axis; let there be a Canal PCE fill'd with a Liquid; this Fluid will deſcend by its Gravity in both Legs towards C, and will not be at reſt till the Preſſure in both Legs be equal. If the Planet be at reſt, the
1359 Height of the Fluid in both Legs will be equal: but if the Planet be mov'd about its Axis P *p*, all the Liquid in the Leg CE will endeavour to
217 recede from the Center by its centrifugal Force,
223 which Force acts contrary to Gravity, and therefore diminiſhes the Gravity; ſo that there is no *Æquilibrium* till CE exceeds CP. Now if the Canal be taken away, the lateral Preſſure of the Fluid, of which the Planet conſiſts, does not change the Gravity towards C, nor the Dif-

ference between the Heights of the Columns
C E, C P;* therefore the Planet is every where * 280
higher in the Æquator than in the Poles, and
acquires by its Motion round its Axis, the Figure of 1362
a Spheroid depreſs'd in its Poles; for the Elevation
is continually diminiſh'd as you go towards the
Pole, becauſe the centrifugal Force is diminiſh'd
by reaſon of the Diminution of the Diſtance
from the Axis.* * 232

If what has been demonſtrated be compar'd
with the Phænomena, it will appear why all the
Bodies in our Syſtem are ſpherical;* but that * 924
this Figure is not exact, but a little chang'd by
their Motion round their Axes,* tho' this can't * 1362
be obſerv'd in moſt of them, may be deduc'd
from Obſervations made upon *Jupiter* and the
Earth. *Aſtronomers have obſerv'd that the Axis of* 1363
Jupiter *is ſhorter than its Æquatorial Diameter*;
altho' this Planet be the greateſt of all the Planets,
it is moved the ſwifteſt about its Axis,* * 962
and therefore this Difference may be obſerv'd.

The Elevation of the Earth at the Æquator is 1364
determin'd by us, altho' perhaps to the Inhabitants
of the other Planets, if there are any, it
may not be more ſenſible than the Elevations on
Mars and *Venus* are to us, which are ſo ſmall
that we cannot perceive them.

Suppoſe the Earth to be fluid, it will acquire 1365
the aforeſaid ſpheroidical Figure;* if the Parts * 1362
cohere towards the Center, the Poſition of the
other Parts will not be chang'd thereby, nor will
it be chang'd if in ſome Places the Parts cohere
together quite to the Surface; ſo that the Surface
of the Sea muſt neceſſarily acquire a ſpheroidical
Figure depreſs'd at the Poles. But
ſince the Shores are every where but a little elevated
above the Surface of the Sea, it is certain
that the Continent acquires the ſame Figure.

Now to meaſure this Elevation, that is, how much the Diameter of the Æquator of the Earth is longer than the Axis, we muſt conſider its Motion round its Axis in the Space of 23 Hours,
* 960 56 Min. 4 Sec.* and ſuppoſing the Earth homogeneous, the Computation will be made in the following Manner.

1366 The Periphery of the Earth is 128202185 *Rhynland* Feet; therefore in one Second of Time, a Point of the Æquator goes thro' 1488 Feet; the Verſed Sine of which Arc is 0,054, a Space which could be gone thro' by a Body in ſuch a Time by the centrifugal Force.

By Gravity, a Body, in one Second, as we have ſhewn before, falls thro' 15,607 *Rhynland* Feet; but theſe Experiments were made at the Diſtance of 48 Deg. from the Æquator E *e*, (*Plate* XXV. *Fig.* 7.) at the Point A, the centrifugal Force at E is to the centrifugal Force at A, as C E to C A, for theſe Lines are very little dif-
* 232 ferent at A B;* let this centrifugal Force be A *b*; having drawn the Perpendicular *b a* to C A continued, let the Force thro' A *b* be reſolv'd into two other Forces directed along A *a*
* 192 and *ab*;* the Gravity is diminiſh'd only by the former, and A *b* is to the Force diminiſhing it, as C A to A B, by reaſon of the ſimilar rectangular Triangles A *b a* and A B C, which have their oppoſite vertical Angles equal at A; therefore the centrifugal Force at the Æquator, with which a Body in one Second goes thro' 0, 054; is to the Force which diminiſhes the Gravity at A, in a duplicate Proportion of the Radius A C to A B, which is the Co-ſine of the Latitude A E of 48 Deg. ſo that from this diminiſhing Force the Body in one Secondgoes thro' 0, 0243; wherefore, if the Earth was at reſt, in falling it would not go thro' 15,607 Feet, but 15,632;

with which Gravity a Body falls under the Poles, becauſe theſe Points are not mov'd. At the Æquator, by the centrifugal Force, a Body goes thro' 0, 054. and falls as much in the ſame Time from the Height of 15,578 Feet; whence it appears that the Gravity under the Poles, is to the Gravity under the Æquator, as 289 to 288.

If *Fig.* 7. repreſents the Figure of the Earth, the Weight of a Column of Liquid C E will be to the Weight of a Column of Liquid C A, the Earth being at reſt, as 289 to 288; for otherwiſe, the Earth moving, there will not be an *Æquilibrium*; becauſe $\frac{1}{289}$ of the Column C E is ſuſtain'd by the centrifugal Force; for the centrifugal Force decreaſes as you come towards the Center, in the Ratio of the Diſtance,* in which Ratio alſo the * 232
Gravity decreaſes;* ſo that in all the Points of * 1233
the Column the ſame Part of the Weight is ſuſtain'd as towards the Surface.

Whence we deduce, that *the Height* C P *at the* 1367
Pole, is to the Height E C *at the Æquator, as* 229 *to* 230; for ſuppoſing this Ratio between the Axis and the Æquatorial Diameter, if a Computation be made of the Gravities in the Places P and E, the Earth being at reſt, they are found to be to one another as 1121,71. to 1120,71.; which Ratio obtains every where in correſpondent Points, that is, which are diſtant from the Center as C P to P E; becauſe in both Legs the Gravity decreaſes in proportion to the Diſtance from the Center.* You have the Weight * 1233
by multiplying the Quantity of Matter by the Gravity; for the Weight encreaſes in a Ratio of both: By multiplying 1121,71. by 229. and 1120,71. by 230. the Products are to one another as 288 to 289; which is the Ratio of the Weights before diſcover'd. The mean Diameter of

* 976 of the Earth is 3400669 Perches,* therefore the
Axis P P is 3393261, and the Æquatorial Di-
ameter E *e* is 3408078 Perches, which exceeds
1368 the Axis by 14817 Perches, *(viz.)* $\frac{1}{230}$, and *the
Æquator is more elevated by* 7408,5.

1369 In this Computation, as we have ſaid, we
have look'd upon the Earth as homogeneous;
but if it be more denſe towards the Center, the
Matter which is added to it may be look'd upon
as a ſeparate Body, from whoſe Center the
Points P and E are unequally diſtant, and to-
wards which therefore the Bodies P and E have
* 1226 a different Gravity;* and the Difference is ſo
much the greater as theſe Differences are greater;
and it will be alſo ſo much the greater in reſpect
of the whole Gravity, as the Quantity of Matter
which is added, or which is the ſame, as the
Denſity is greater towards the Center is greater.

It is plain that the Forces of Gravity at the
Poles and the Æquator differ from one another
more than $\frac{1}{289}$ Part, by comparing together Experi-
ments made at ſeveral Diſtances from the Æqua-
tor, by the Help of Pendulums, by which the
Forces of Gravity may be compar'd together,
* 164 as we have ſhewn;* and which Difference is truly
165 nearly double that which is found by Computa-
1370 tion; whence it follows, that *the Elevation of the
Æquator is nearly double that which we have de-*
* 1368 *termin'd to be* 7408,5. *Perches.**

Now if we conſider the ſpheroidical Figure
1371 of the Earth, we ſhall ſee that *heavy Bodies don't
tend directly to the Earth's Center*, unleſs at the
Poles and the Æquator, *but every where perpen-
dicularly to the Surface* of the Spheroid; for a
Liquid will not be at reſt unleſs its upper Surface
forms a right Angle with the Direction of heavy
* 272 Bodies;* and the Figure of a Spheroid is
form'd by the Surface of a quieſcent Fluid. We

alſo deduce this Direction of heavy Bodies from 1372
the centrifugal Force, (*Plate* XXV. *Fig.* 7.) The
Body A, by its Gravity, tends towards C, and
is carried by its centrifugal Force along A *b*;
this Force at the Point A is to the Gravity
along A C, as 1 to 430,8. having form'd a Parallelogram with the Sides A *c* and A *b*, ſuppoſing
theſe to one another as 430,8. to 1, the Diagonal will ſhew the Direction of heavy Bodies,* * 190
forming a ſmall Angle with the Line A C. The
Force along A *b* encreaſes as you go towards
the Æquator, whereby this Angle is increas'd,
but is diminiſhed by the Encreaſe of the Angle
C A *b*; ſo that in the Æquator, where the centrifugal Force is greateſt, the Direction of heavy Bodies coincides with E C; at the Pole it
coincides with P C; becauſe there is no centrifugal Force there.

In this ſpheroidical Figure, *the Latitude of the* 1373
Place is determin'd by an Angle, as A C E, *which
is made with the Æquator, by a Line drawn from
the Place to the Center.* Dividing this whole Arc
PA E, by this Method, into 90 Parts, that is,
into Degrees, it will eaſily appear, that *going* 1374
*towards the Poles, the Degrees are encreas'd on the
Surface*; but this Difference is ſo very ſmall,
that in meaſuring Degrees that are not very diſtant, it cannot be diſcover'd; becauſe the Error ariſing from the Make and Uſe of the Inſtruments, exceeds this Difference. Whence Degrees meaſur'd at the South and North of *France*,
as alſo in *England*, differ little from one another,
and the middle one is the leaſt of all; wherefore
nothing can be concluded concerning the Earth's Fi- 1375
gure from theſe Meaſures.

CHAP.

CHAP. XVIII.

The Phyſical Explanation of the Motion of the Axis of the Earth.

THAT the Nodes of the Moon go back,
*1341 that is, are mov'd in *Antecedentia*,* and
that the Inclination of its Orbit is liable to
1347 Change, we have already demonſtrated; let
us conceive ſeveral Moons to be at the ſame
Diſtance, revolving in equal Times about the
Earth, in a Plane inclin'd to the Plane of the
Ecliptic; it is plain they will all be agitated by
the ſame Motions: Let us conceive the Number
of the Moons to be encreas'd, ſo as to touch
one another, and form a Ring, whoſe Parts cohere;
whilſt one Part of the Ring is attracted,
to encreaſe the Inclination, the other Part is
1376 agitated by a contrary Motion to diminiſh its
1345 Inclination; the greater Force in this Caſe pre-
1377 vails, that is, *in the Motion of the Line of Nodes,
from the Quadratures towards the Syzygies, the Inclination
of the Ring is diminiſh'd in each of its Revo-
1349 lutions; and it is the leaſt of all, when the Line of
*1350 Nodes is in the Syzygies.** On the contrary, *its
Inclination is encreas'd when the Line of Nodes is
*1351 carried from the Syzygies towards the Quadratures;**
1378 *and it is the greateſt of all, when the Line of the
1352 Nodes is in theſe laſt. The Line of the Nodes is
1341 continually carried in Antecedentia, *unleſs when it
1344 is at reſt in the Syzygies.**

1379 *If the Quantity of Matter in the Ring be diminiſh'd, its Motions will not be chang'd*; becauſe they
depend upon Gravity, which acts equally upon
1027 every Particle of Matter.

If the Diameter of the Ring be diminiſh'd, theſe 1380
Motions are diminiſh'd in a Ratio of this Diminution,*
but none of them wholly vaniſh;* 1354
and *it is agitated by the ſame Motions.*

Let us conceive the Earth to be ſpherical; 1381
and in the Plane of the Æquator, which makes
an Angle of 23 Deg. 29 Min. with the Plane of
the Ecliptic, let there be a Ring, revolving in
the ſame Time as the Earth; let it be diminiſh'd
ſo as to touch the Earth, and cohere with
it; by this the aforeſaid Motion of the Ring
will not be deſtroy'd; for ſince the Earth is kept
in a determinate Situation by no Force, it yields
to the Impreſſions of the Ring, whoſe Agitations
are yet diminiſh'd, the Matter to be mov'd
being encreas'd, and the moving Power remaining
the ſame.

And this is truly the Caſe, for the Figure of
the Earth is ſpherical, encompaſs'd with a Ring
at the Æquator, whereby the Earth is more elevated
towards the Æquator,* the Line of Nodes *137[illegible]
of which Ring, is the Section of the Planes of
the Æquator and Ecliptic. Whence we deduce
the following Concluſions.

In the Æquinoxes, the Inclination of the 1382
Æquator is leaſt of all;* and therefore *the Inclination *1377
of the Axis is the greateſt; for it makes a
right Angle with the Plane of the Æquator*. *1075
The Inclination of the Æquator is encreas'd,
that is, *the Inclination of the Axis is diminiſh'd, till* 1383
*the Sun comes to the Solſtices, where this Inclination of
the Axis is leaſt of all*, and that of the Æquator
the greateſt.* Therefore *twice in a Year the Inclination *1377
*of the Axis of the Earth is diminiſh'd, and
twice encreas'd.* And *the Section of the Plane of the* 1384
Æquator with the Plane of the Ecliptic, which *is* 1385
*at reſt in the Æquinoxes, the reſt of the Time is
mov'd in* Antecedentia.* *1378

1386 The Plane of the Æquator is inclined to the Plane of the Moon's Orbit; for it makes a ſmall Angle with the Plane of the Ecliptic:* And therefore the Moon acts in the ſame manner upon the Ring as the Sun; and altho' the Moon be leſs, yet, becauſe it is much leſs diſtant than the Sun, it exerts a greater Action upon the Ring. *969

1387 Wherefore alſo *the Inclination of the Axis of the Earth to the Plane* of the Moon's Orbit* (and conſequently to the Plane *of the Ecliptic*) *is twice chang'd in every Revolution, and twice reſtor'd by the Action of the Moon: And the Section of the Plane of the Æquator,* with the Plane of the Moon's Orbit,* *is carried in* Antecedentia: From which Motion neceſſarily follows, that the Section of the Plane of the Æquator, *with the Plane of the Ecliptic changes its Place.* *1384 *1385

1388 *The Changes of the Inclination of the Axis are too ſmall to be obſerved; but the Change of Place of the* 1389 *Line of the Equinoxes, and the Motion of the Axis* which follows from it, being always carried the ſame way, *at laſt become ſenſible*; and from theſe follow the Phænomena before explain'd.* *1185 1186

CHAP. XIX.

Concerning the Tides.

THAT we may explain the Tides from the Principles already laid down, we muſt conſider, that the Earth, as alſo all Bodies near it, gravitate towards the Moon;* therefore the Particles of Water in the Earth's Surface, which tend towards the Center of the Earth, (for here we neglect the Conſideration of N° 1371.) are carried with it towards the Moon. Since alſo the ſolid Maſs of the Earth is carried towards the Moon, according to the Laws, which wou'd obtain *1206

obtain, if all the Matter of which it conſiſts
was collected in its Center*; *what has been demonſtrated* *1126
in Chap. 16. *of the Action of the Sun* 1390
upon the Moon falling towards the Earth, whilſt
with the Earth it goes towards the Sun, *may be*
applied to the Action of the Moon upon the Particles
of Water in the Earth's Surface, which don't cohere
with the Maſs of the Earth, but tend towards
its Center, and continually with its Maſs
fall towards the Moon; by which Force, as we
have ſhewn*, the Earth is kept in its Orbit, *1280
about the common Center of Gravity of the
Earth and the Moon.

Plate XXV. *Fig.* 1.] Let S be the Moon; 1391
A L B *l* the Surface of the Earth, whoſe Maſs
tends towards the Moon, as if it was all collected
at T; by the Action of the Moon, the
Particles of Water A and B, acquire a greater
Gravity towards T*; on the contrary, the Par- *1287
ticles at L, *l*, loſe of their Gravity*; whence *1296
we deduce, that if the whole Earth was cover'd
with Water, there wou'd not be an *Æquilibrium*,
unleſs this Water was more elevated in
the Points L and *l*, than in a whole Circle 90
Deg. diſtant from theſe Points; and therefore
paſſing thro' the Points A and B. Therefore 1392
by the Action of the Moon, the Water acquires a
ſpheroidical Figure, form'd by the Revolution of an
Oval about its greater Axis, which being continu'd,
goes thro' the Moon.

Let us ſuppoſe the Moon in the Æquator;
all the Sections of the Earth which are parallel
to the Æquator; as they are alſo parallel to the
Axis of the Spheroid*, are oval, whoſe greater *1392
Axes paſs thro' the Meridian of the Moon;
whence it follows, that *the Earth being at reſt, in* 1393
any Circle of Latitude, the Water is more elevated

in the Meridian in which the Moon is, and in the oppoſite Meridian, than in the intermediate Places.

DEFINITION

1394 A Lunar Day, *is the Time ſpent between the Moon's going from the Meridian and coming to it again.* This Day is divided into 24 Lunar Hours: It is 50 Minutes longer than the Natural Day.

From the Motion of the Earth round its Axis, every Lunar Day every Place paſſes thro' the Meridian of the Moon and the oppoſite Meridian, that is, twice paſſes thro' that Place,
1395 where the Water is rais'd *by the Action of the Moon*, and twice thro' that Place where the
1393 Water is depreſs'd by the ſame Action; and ſo *in a Lunar Day the Sea is twice elevated, and twice depreſs'd, in any aſſign'd Place.*

1396 By the Motion of the Earth round its Axis, the elevated Water continually recedes from the Meridian of the Moon; yet by the Action of the Moon, the Axis of the Spheroid paſſes
1392 thro' the Moon; therefore the Water is continually agitated, that the Elevation, which (on Account of the Motion of the Earth) is remov'd, may be brought under the Moon. Therefore the Water continually flows from A and B (*Plate* XXV. *Fig. 6.*) towards L and *l*, whilſt by the Motion of the Earth the Elevation is carried from L towards B, and from *l* towards A; that is, between L and B, as alſo between *l* and A, there are two contrary Motions, by which the Water is accumulated; ſo that the greateſt Elevations are between theſe Points, (*viz.*) not directly under the Moon, but on one Side of that Point, and likewiſe aſide of
1397 the oppoſite Point. That is, in any Place, *the Water is moſt elevated, two or three Hours after the Moon*

Moon has paſs'd the Meridian of the Place, or the oppoſite Meridian.

The Elevation towards the Moon a little exceeds 1398
*the oppoſite one**. *The Aſcent of the Water is dimi-* *1390
niſh'd, as you go towards the Poles, becauſe there is 1295
no Agitation of the Water there.

What has been demonſtrated in Relation to 1399
the Moon, may be applied to the Sun; there- 1400
fore *from the Action of the Sun, every Natural Day,* 1401
*the Sea is twice elevated, and twice depreſs'd**. *This* *1395
Agitation is much leſs, on account of the immenſe
Diſtance of the Sun, *than that which depends upon*
the Moon; yet *it is ſubject to the ſame Laws.* 1402

The Motions which depend *upon the Action of* 1403
the Moon and Sun, are not diſtinguiſh'd but confounded; and from the Action of the Sun, *the Lunar Tide is only chang'd; which Change varies*
every Day, by reaſon of the Inequality between 1404
the Natural and Lunar Day*. *1394

In the Syzygies the Elevations, from the Actions 1405
of both Luminaries, concur, and *the Sea is more elevated; the Sea aſcends leſs in the Quadratures;* for where the Water is elevated by the Action of the Moon, it is depreſs'd by the Action of the
Sun, and ſo on the contrary. Therefore, *whilſt* 1406
the Moon paſſes from the Syzygy to the Quadrature, the daily Elevations are continually diminiſh'd: On the contrary *they are encreas'd, when the Moon*
moves from the Quadrature to the Syzygy. At a New 1407
Moon alſo, *cæteris paribus, the Elevations are greater,*
and thoſe that follow one another the ſame Day, are *1398
*more different than at a Full Moon**. 1402

The greateſt and leaſt Elevations are not obſerv'd, 1408
till the ſecond, or third Day after the New or Full Moon; becauſe the Motion acquir'd is not preſently deſtroy'd from the Attrition, and other Cauſes, by which acquir'd Motion the Aſcent of the Water is encreas'd, altho' the Action by

which the Sea is rais'd be diminiſh'd; ſomewhat like to what we have demonſtrated elſewhere *1174 concerning Heat*.

If now we conſider the Luminaries receding from the Plane of the Æquator, we ſhall per-1409 ceive that *the Agitation* is diminiſh'd, and *becomes leſs, according as the Declination of the Luminaries becomes greater.* Which plainly appears, if we conceive them to be in the Poles; for then the Axis of the ſpheroidical Figure coincides with the Action of the Earth; and all the Sections that are parallel to the Æquator, are perpendicular to the Axis of the Spheroid; and therefore circular. So that the Water, in every Circle of Latitude, will have every where the ſame Elevation; and ſo in the Motion of the Earth, the Height of the Sea is not chang'd in particular Places. If the Luminaries recede from the Pole, it's eaſy to find, that the Agitation will be more and more encreas'd, till it be the greateſt of all, the Spheroid revolving about a Line perpendicular to the Axis, the Axis of the Spheroid being ſuppos'd in the Plane of the Æquator.

1410 Hence it is plain, why *in the Syzygies, near the Æquinoxes, the Tides are obſerv'd to be the greateſt,* both Luminaries being in or near the Æquator.

1411 *The Actions of the Moon and Sun are greater, the* *1354 *leſs thoſe Bodies are diſtant from the Earth**; but *1390 when the Diſtance of the Sun is leſs, and it is in the South Signs, often both the greateſt Æquinoctial Tides are obſerv'd in that Situation of the Sun; that is, before the Vernal, and after the Autumnal Æquinox, which yet does not happen every Year; becauſe ſome Variation may ariſe from the Situation of the Moon's Orbit, and the Diſtance of the Syzygy from the Æquinox.

Plate XXV. *Fig.* 8.] *In Places diſtant from the Æquator, as the Luminaries recede from the Æquator, the Elevations that happen the ſame Day are unequal.* Let P P be the Axis of the Earth, E E the Æquator, L *l* a Circle of Latitude; A B the Axis of the ſpheroidical Figure which the Water forms: When a Place in the Circle L *l* is given at L or *l*, it is given in the ſame Meridian with the Axis of the Spheroid, and the Water is moſt elevated, in both Caſes; yet at L it is more elevated than at *l*; for C L exceeds C *l*, which Lines meaſure the Heights of the Waters, that is, their Diſtances from the Center: Theſe Lines wou'd be equal if A L and B *l*, (which are the Diſtances from the Axis of the Spheroid) were equal. But C *l* is leſs, becauſe B *l* exceeds A L, which ariſes from the Inclinatiou of the Axis of the Spheroid to the Æquator. 1412

As long as the Moon is on the ſame Side of the Æquator in any Place, that is, towards the Line C A continu'd, *the Elevation of the Water is obſerv'd to be greateſt every Day, after the Moon has paſs'd the Meridian of the Place*, for there is the greateſt Elevation when the Place is come to L; but *if the Æquator* ſeparates, or *is between* the *Moon and the Place*, of which we ſpeak, that is, if the Moon be towards the Line C B continu'd, the Water again at L will come to the greateſt Height, and *every Day, the greateſt Elevation of the Sea will be, after the Moon has paſs'd thro' the oppoſite Meridian.* 1413 1414

All Things which have been hitherto explain'd, wou'd exactly obtain, if the whole Surface of the Earth was cover'd with Sea; but ſince the Sea is not every where, ſome Changes ariſe from thence, not indeed in the open Sea; becauſe the Ocean is extended enough to be ſubject to the Motions we have ſpoken of. But

1415 *the Situation of the Shores, the Streights, and many other Things depending upon the particular Situation of the Places, diſturb theſe general Rules.* Yet it is plain from the moſt general Obſervations, that the Tide follows the Laws which we have explain'd. What remains is, to determine the Forces with which the Sun and Moon act upon the Sea, that it may appear, that they are able to produce the Effects which we have mention'd; and that the Actions of thoſe Bodies upon Pendulums and other Bodies are inſenſible.

1416 The Encreaſe or Addition to the Gravity of the Moon in the Quadratures, from the Action of the Sun, is to the Gravity of the Moon to-
1291 wards the Earth, as 1 to 178,73. In which Computation we have ſuppos'd the Mean Diſtance of the Moon, from the Center of the
1285 Earth, to be 60 Semidiameters of the Earth; therefore the Gravity of the Moon is to the Gravity on the Earth's Surface, as 1 to 60 × 60
1208 = 3600. Therefore the above-mention'd Encreaſe is to the Gravity on the Earth's Surface, as 1 to 643428, in which Computation there is an Error to be corrected.

This Computation wou'd be exact, if the Encreaſe of which we ſpeak, was to the Force, with which the Earth deſcends towards the Sun, as the Diſtance of the Moon (which is 60 Semidiameters of the Earth) to the Diſtance of
1287 the Earth from the Sun; but it is as the true Mean Diſtance of the Moon, which is 60 $\frac{1}{2}$ Semidiameters of the Earth, to the Diſtance of the Earth from the Sun. Wherefore the Encreaſe that we have juſt determin'd, ought to be $\frac{1}{120}$ Part encreas'd and will be to the Force of Gravity on the Earth's Surface, as 1 $\frac{1}{120}$ to 643428, or as 1 to 638110,4.

This Encreaſe of the Gravity of the Moon in the Quadratures from the Action of the Sun,

on

is to the Encreaſe of the Gravity of the Water
on the Earth's Surface, in Places which are 90
Deg. diſtant from the Sun, (from the ſame
Action of the Sun) as 60½ to 1*. Therefore this* 1288
Encreaſe of the Gravity is to the Gravity of the
Water, as 1 to 38605679. The Diminution of
the Gravity under the Sun, and in the oppoſite
Place is double this Encreaſe*; therefore it is to* 1296
the Gravity as 1 to 19302839, and *the* whole *Change* 1417
in the Gravity, ariſing from the Action of the Sun,
is to the Gravity itſelf as 1 *to* 12868560.

In order to compare the Action of the Moon 1418
with the Action of the Sun, we muſt make Experiments in Places, in which, by reaſon of the
Narrowneſs, the Sea is ſenſibly rais'd. Near
Briſtol at the Autumn and Spring, at which
Times the Agitation of the Sea is greateſt*, the* 1409
Water aſcends in the Syzygies about 45 Feet,
more or leſs, in the Quadratures about 25 Feet,
more or leſs. Which Numbers are to one another as 9 to 4.

The Determination of the Forces, which we
wou'd find, if the greateſt and leaſt Elevations
were exactly at the Time of the Syzygies,
wou'd be very eaſy, which we have ſhewn before not to happen ſo.* * 1408

The Diſtance of the Moon from the Syzygy, or the Quadrature, is not always the ſame in the greateſt or leaſt Elevation; for this Diſtance varies, becauſe the Moon is ſometimes more, and ſometimes leſs diſtant from the Meridian, when it goes thro' the Syzygy or Quadrature. The Mean Diſtance of the Moon from the Syzygy, or Quadrature, to which the aforeſaid Obſervations ought to be referr'd, is about 18 Deg. 30 Min. ſo that the whole Action of the Sun, neither conſpires with the Action of the Moon in the Syzygies, nor acts contrary to it in the Quadratures. Alſo in ſuch a Caſe, if at

the Syzygy, both the Luminaries be in the Æquator, in the ſaid Diſtance from the Quadrature, the Declination of the Moon is 22 Deg. 13 Min. more or leſs; whereby the Force of the Moon to
1409 move the Sea is diminiſh'd. Beſides, *cæteris paribus*, the Diſtance of the Moon from the Earth at
1310 the Syzygies is leſs, than at the Quadratures;
1311 whence alſo the Action of the Moon is diminiſh'd
1411 at the Quadratures: By attending to all which Things we may diſcover, that *the Mean Force of*
1419 *the Sun to move the Sea, is to the Mean Force of the Moon to move the ſame, as* 1 *to* 4,4815. But the Force of the Sun is to the Force of Gravity as
14 7 1 to 12868560; wherefore *the Force of the Moon is to the* ſame *Force of Gravity, as* 1 *to* 2871485.
1420 From whence it follows, that theſe Forces of the Moon and Sun are too ſmall, to be ſenſible in Pendulums and other Experiments; but it is eaſily prov'd, that they are capable of agitating the Sea.

By diminiſhing the Gravity $\frac{1}{289}$ part, the Sea
*1368 is rais'd to the Height of 88902 *Rhynland* Feet.*
1417 For each Perch contains 12 Feet; whence by
1421 the Rule of Proportion*, we find that *the Action*
1422 *of the Sun changes the Height of the Sea two Feet,*
*1419 *and that the Action of the Moon changes it* 8,95*; *and that from the join'd Action of both, the Mean Agitation is of about eleven Feet*, which agrees pret-
1423 ty well with Obſervations; for in the open Ocean, as the Sea is more or leſs open, the Water is rais'd to the Height of Six, Nine, Twelve, or Fifteen Feet; in which Elevations alſo there is a Difference ariſing from the Depth of the Waters. But thoſe Elevations which far exceed
1424 theſe, happen, *where the Sea violently enters into Streights or Gulphs*; where *the Force is not broken, till the Water riſes higher.*

CHAP.

CHAP. XX.

Of the Moons Denſity and Figure.

THE Forces of the Sun and Moon, for 1425
giving Motion to the Sea, are to one another
in a Ratio compounded of the Ratio of the
Quantities of Matter in theſe Bodies *(for all the * 1207
Particles of Matter act) and the inverſe Ratio of
the Cubes of the Diſtances of the Sun and Moon
from the Earth. * * 1390

The Quantities of Matter are in a Ratio compounded 1402
of the Ratio of the Bulks, that is, of 1354
the Cubes of the Diameters, and the Ratio of
the Denſities; * wherefore the Forces above- * 288
mention'd, are directly as the Denſities and the 79
Cubes of the Diameters, and inverſely as the
Cubes of the Diſtances.

The apparent Diameters of Bodies, that is, the Angles under which they are ſeen, encreaſe as the Diameters themſelves, and diminiſh as the Diſtances; that is, they are directly as the Diameters, and inverſely as the Diſtances; therefore the Ratio compounded of the Ratio's of the Cubes of the apparent Diameters *of the Sun and Moon*, and of the Ratio of the Denſities, will be the Ratio of the Forces, whereby thoſe Bodies
act upon the Sea. Therefore the *Denſities* of 1426
thoſe Bodies *are directly as the Forces, whereby they move the Sea, and inverſely as the Cubes of their apparent Diameters:* and dividing the Forces by the Cubes of thoſe Diameters, you have the Ratio of the Denſities.

The Force of the Sun is to the Force of the
*1419 Moon, as 1 to 4,4815 *; the Mean apparent Diameter of the Sun is 32 Min. 12 Sec. and the Mean apparent Diameter of the Moon is 31 Min. 16 $\frac{1}{2}$ Sec. that is, they are to one another, as
1427 3864 to 3753. Therefore *the Denſity of the Sun is to the Moon's Denſity as* 10000 *to* 48911: which Denſity of the Moon may be compar'd with
*1260 the Denſities of *Jupiter*, *Saturn* and the Earth, * and the Moon is denſer than the Earth.

The Quantities of Matter in two Bodies are to one another in a Ratio compounded of the
79 Denſities and Bulks *; that is, if the Body be a Sphere, in a Ratio compounded of the Den-
1428 ſities and the Cubes of the Diameters.

*1427 *The Denſities of the Moon and Earth, are to one*
1260 *another*, as 48911 to 39214 *; the Diameters as 11 to 40,2. therefore the *Quantities of Matter* in thoſe Bodies, *are as* 1 *to* 39,13. Tho' the Denſities be diſcover'd, if you ſuppoſe the Bodies to be homogeneous; yet the Quantities of Matter will be rightly defin'd, tho' the Bodies are not homogenous: for we determine the Denſity which that Body wou'd have, if the Matter of which the Body really conſiſts, was equally diffus'd all
1429 over it.

The Gravities on the Surfaces of the Earth and
*1230 *Moon are* determin'd, by multiplying the Denſities by the Diameters *, that is they are to one another, as 2, 93 to 1, or *as* 407,8. *to* 139,2. Which Number alſo does expreſs the Relation of Gravity on the Surface of the Moon, with the Gravity on the Surfaces of the Sun, *Jupiter*
*1258 and *Saturn.* *
1430

The common Center of Gravity of the Moon and Earth, about which both Bodies are mov'd, is determin'd; for its Diſtance from the Center of

the Earth, *is to the Diſtance* between the Centers
of both Bodies, as the Quantity of Matter in the
Moon to the Quantity of Matter in both Bodies
; therefore 40,13. is to 1: as the Diſtance 234
of the Moon from the Earth, is to the requir'd 235
Diſtance of the Center of Gravity *from the Center
of the Earth,* which is found to be *of* 5126950
Perches, as is deduc'd from the known Diameter
of the Earth *, and the Diſtance of the * 976
Moon.

To determine the Figure of the Moon, we 1431
muſt examine what Figure it wou'd have if it
was fluid *. If we conſider the Moon alone at * 1358
reſt, it wou'd be ſpherical * : If we conſider the * 1359
Action of the Earth upon the Moon, the Moon
wou'd acquire the Figure of a Spheroid, whoſe
Axis wou'd go thro' the Earth *. The Force * 1392
of the Earth for changing the Figure of the
Moon, is to the Force of the Moon upon the
Earth, as 39,13. to 1 *. and as the Diameter of * 1428
the Moon to the Earth's Diameter *, which are * 1207
to one another, as 11 to 40,2. and it is a Ratio 1390
compounded of theſe 10,7. to 1. This Force 1354
of the Moon, is to the Gravity upon the
Earth's Surface, as 1 to 2871485 *; which * 1420
Gravity on the Earth's Surface, is to the Gravity
on the Surface of the Moon, as 407,8, to 139,2 *. * 1429
or as 2871485, to 980028; wherefore *the Action
of the Earth for changing the Moon's Figure, is to
the Gravity upon the Moon's Surface, as* 10,7. *to* 1432
980028, *or as* 1 *to* 91524, the Gravity being
chang'd on the Earth's Surface, by $\frac{1}{2871485}$ part,
the Water is raiſed 8,95 Feet *; and therefore, if * 1420
Gravity was to be chang'd $\frac{1}{91524}$ part, the Eleva- 1422
tion wou'd be of 280,7 Feet, as is found by the
Rule of Three. If, keeping this Diminution of
Gravity, we conſider a leſs Body, this Height
muſt

muſt be diminiſh'd in proportion to the Diameter: therefore, from the Action of the Earth, the Elevation of the Moon is of 76,8 Feet: and if the Moon be homogenous, *there will not be an Æquilibrium, unleſs the Axis of the Spheroid exceeds the Diameter which is perpendicular to it* 153,60 Feet. 1433

1434 *The Elevation of the Moon* from the Action *of the Earth*, may be diſcover'd by one ſingle Proportion, by knowing the Elevation of the Sea from the Moon's Action; for theſe Elevations *are in a duplicate inverſe Ratio of the Gravities on the Surfaces of thoſe Bodies.*

1435 If, ſuppoſing this to be the Figure of the Moon, we conceive the Parts to cohere, *there will not be an Æquilibrium between the Parts of the Moon, unleſs* the Axis of the Spheroid be directed towards the Earth; whence we ſee the reaſon why *the Moon always turns the ſame Face towards the Earth*; by which continual Agitation, the

1436 Moon has at laſt acquir'd *the Motion about its Axis*

*970 of which we have before ſpoken *: which Mo-

1092 tion *muſt neceſſarily be perform'd in the ſame Time, as the Moon performs one Revolution*; for from the Action abovemention'd, it muſt neceſſarily adapt itſelf to ſuch a Celerity; for if the Celerity was greater, it wou'd be continually retarded by the Force, whereby the ſame Face is always directed towards the Earth; and if this Celerity was leſs, it wou'd be continually accelerated. Yet this Force is not great enough, ſenſibly to diſturb the Æquability of the Motion acquir'd

1437 about the Axis, every Revolution: Therefore *the Motion about the Axis is equable, tho' the Moon*

*966 *be mov'd in its Orbit by an unequal Motion* *. The Poſition alſo of the Moon's Axis, cannot be ſo chang'd by the Force abovemention'd, as to *front. page 284.* *Plate 25.*

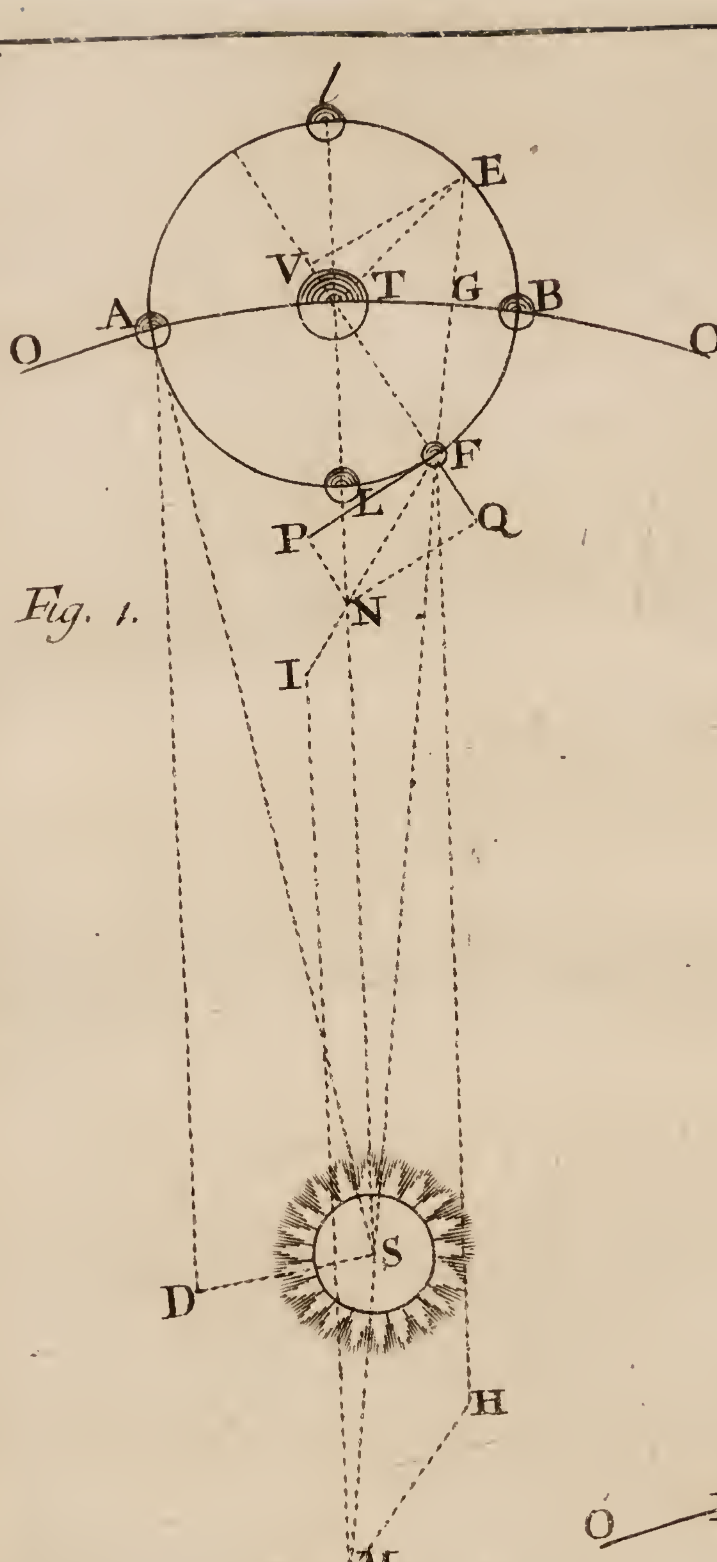

E
V
T
G
B
A
O
O
F
L
P
Q
N
I
S
D
H
M

Fig. 1.

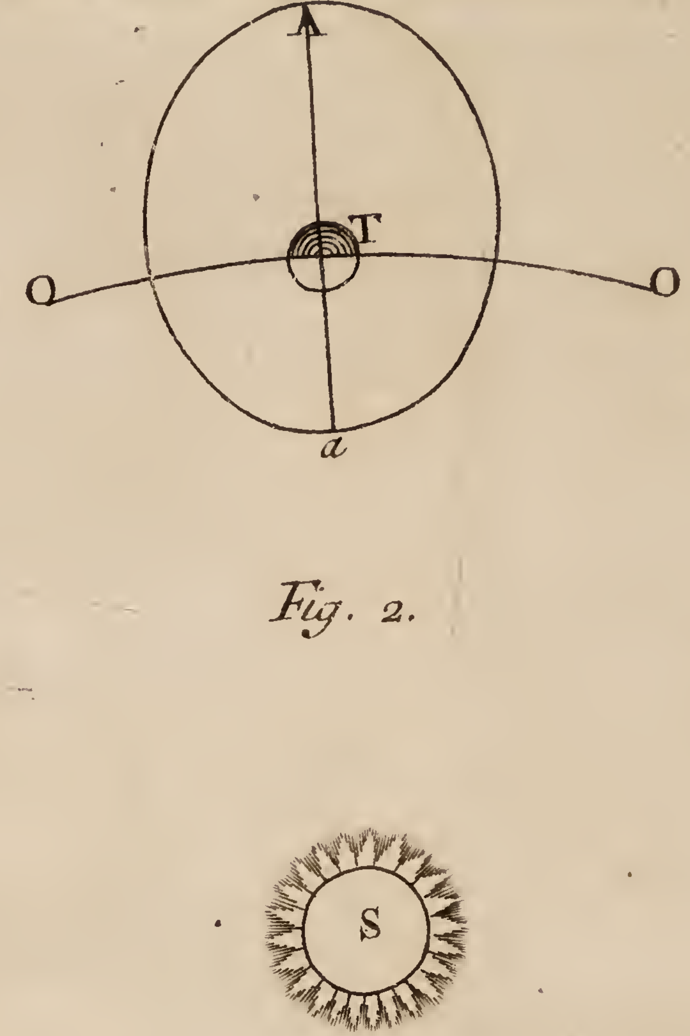


Fig. 2.

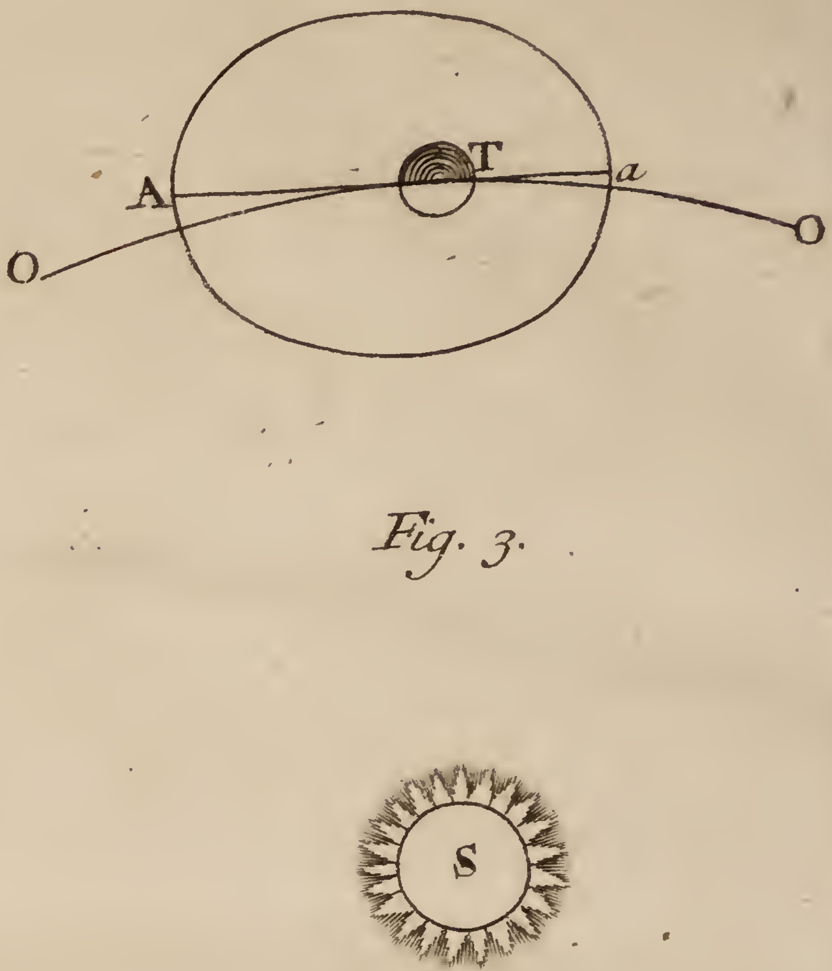


Fig. 3.

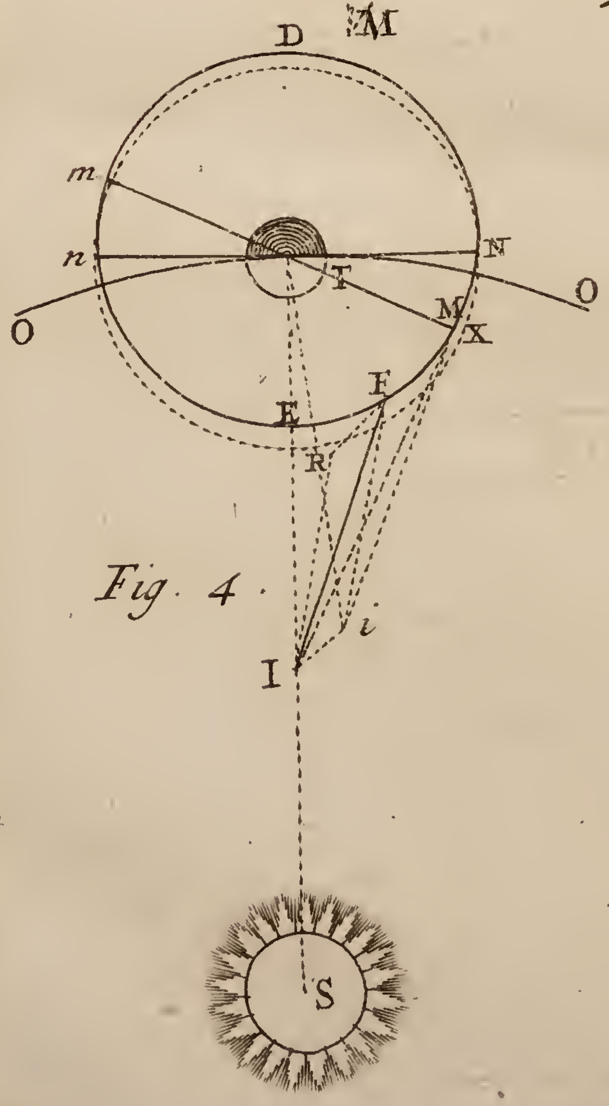

D
m
n
N
O
O
T
M
X
E
F
R
I
i
S

Fig. 4.

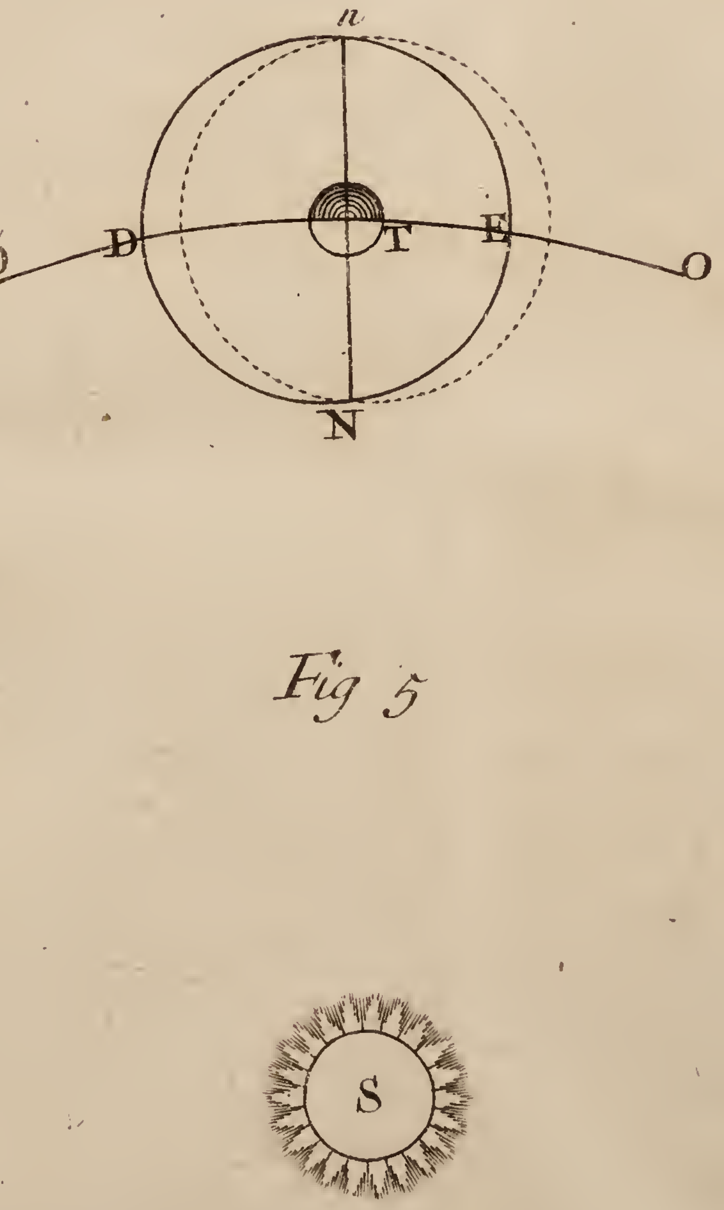


Fig 5

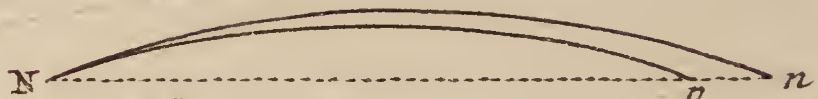


Fig. 6.

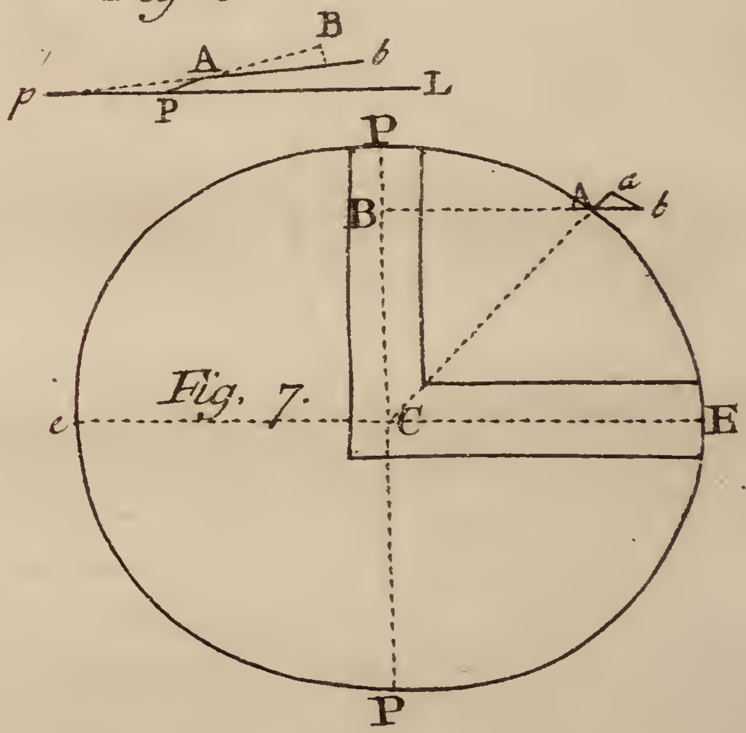

B
A
b
p
P
L
P
B
A
a
b
e
C
E
P

Fig. 7.

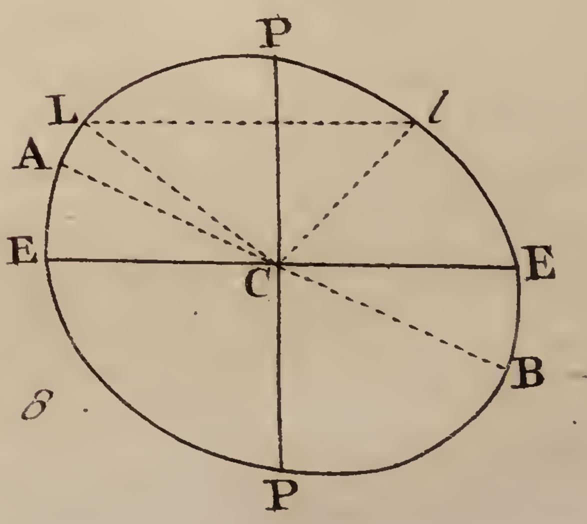


Fig. 8

Vol. 2.

become perpendicular to the Plane of the Orbit, when its Inclination is chang'd *; *1345 1438 therefore *the Axis of the Moon is ſometimes inclin'd to the Plane of the Orbit*, as we have before ſhewn. * *1093

The End of the Fourth Book.

A N

INDEX.

THE Numbers (1.) and (2.) refer to the Firſt and Second Volume. *p.* ſtands for Page, and *n.* for the Number in the Margin.

A

ACceleration *of heavy Bodies* (1.) p. 52. n. 129. and the following. Acceleration *of Bodies rolling down upon an inclin'd Plane*, p. 58. n. 144. and fol. n. 135 and fol.

Æolipile, (2.) *p.* 21. *n.* 606, 607.

Æquation, *of Time.* (2.) p. 194, 1145.

Æquator, (2.) *p.* 181. *n.* 1075. *p.* 188. *n.* 1114.

Æquinox, (2.) *p.* 15. *n.* 1155.

—— *Præceſſion of the* Æquinoxes, *p.* 201. *n.* 1186. *p.* 203. *n.* 1193.

—— *the Explanation of this Motion*, p. 27. n. 1382. and f.

Air *ranked amongſt the Fluids*, (1.) p. 209. n. 417 and fol.

—— *weighed*, p. 223. n. 442.

—— *endowed with Elaſticity*, p. 212. n. 426. and fol.

—— *conſiſting of ſeparated Particles.* p. 216. n. 431.

—— *Experiments relating to it*, p. 223. n. 442. and fol.

—— *The Vehicle of Sound*, p. 249. n. 504.

—— *Its Action upon Fire*, See *Fire.*

Air Pump, (1.) *p.* 219. *n.* 435. and fol.
Altitude or *Height of the Stars,* (2.) p. 187. n. 1105.
—— *of the Pole,* p. 190. n. 1126.
Amplitude *of the Stars,* p. 187. n. 1104.
Angle *of Incidence,* (2.) p. 28. n. 621.
—— *of Refraction,* ibid. n. 623.
—— *of Reflection,* p. 81. n. 781.
Animals cannot live without Air, (1.) p. 232. n. 463.
—— *in condens'd Air,* p. 233. n. 465.
Aphelia *of Planets,* (2.) p. 152. n. 935.
Apſides *of Planets,* (2.) p. 152. n. 937.
The Line of the Apſides, p. 152. n. 938.
Aſcent of *Fluids in capillary Tubes,* (1.) p. 13. n. 35.
—— *even in a Vacuum,* ibid. n. 36.
—— *between two Glaſs Planes,* p. 14. n. 37, 38.
Aſteriſms, *p.* 202. *n.* 1190. and fol.
Atmoſphere, (1.) *p.* 209. *n.* 418.
Attraction, (1.) *p.* 11. *n.* 31.
—— *the Laws of it,* ibid.
—— *from Gravity,* (2.) p. 207. n. 1210.
The Space of Attraction, (2.) p. 31. n. 632.
Auges. See *Apſides.*
Axioms *concerning Motion,* (1.) p. 21. n. 58. and fol.
Axis *of a Planet,* (2.) p. 154. n. 949.
The Motion of the Axis *of the Earth:* ſee *the Preceſſion of the Æquinoxes*
Axis in Peritrochio, (1.) p. 38. n. 112.
—— *the Properties of it,* p. 39. n. 113. and fol.
Axis *of a Balance,* p. 28. n. 24.

B

Balance, *its Properties,* (1.) p. 28. n. 87. and fol.
—— *the Perfection of one,* p. 34. n. 102.
—— *Falſe* Balance, *p.* 30. *n.* 92.
—— *Hydroſtatical* Balance, *p.* 134. n. 271.
—— *Roman* Balance, (1.) *p.* 30. *n.* 91.
Blackneſs : ſee *Reflection.*
Black *Bodies grow warm ſooner than Bodies of other Colours,* (2.) p. 145. n. 909.
Body, *its Properties,* (1.) p. 4. n. 8. and fol.

Burning *Glaſſes*, (2.) p. 56. n. 703.

C

Celerity, (1.) *p.* 20. *n.* 53.
——— *relative*, p. 75. *n.* 175.
Center *of a Balance*, (1.) p. 28. n. 85.
Center *of Gravity*, (1.) p. n. 95.
——— *Its Properties*, ibid. n. 96. and fol.
——— *of Oſcillation*, p. 65. n. 161.
——— *of Percuſſion*, p. 65. n. 162.
Central *Forces*, (1.) p. 105. n. 220.
——— *their Properties*, p. 105, n. 221. and fol.
——— *compar'd together*, p. 112. n. 231. and fol.
Centrifugal *Force*, (1.) p. 104. n. 218.
Centripetal *Force*, (1.) p. 105. n. 219.
Dark Chamber, (2.) p. 59. n. 711. p. 92. n. 817.
The Law of Coheſion, (1.) p. 11. n. 31.
Colour *of Objects*, (2.) p. 116. n. 859.
——— *of Rays*, ibid. n. 860.
This laſt Colour *is always unchangeable*, p. 117. n. 863. and fol. p. 123. n. 869.
The Order of Colours, *according to their different Refrangibility*, p. 117. n. 861.
——— *mix'd* Colours, *p.* 127. *n.* 873. 874.
From whence Colours *come to be dull or lively*, p. 146. n. 911. 915.
Why Colours *vary in ſome Bodies according to the Situation of the Eye*, ibid. n. 914.
The Change of Colours *in Liquids mix'd*, p. 146. n. 916.
A Liquid appearing of a different Colour, *according as it is ſeen by reflected or tranſmitted Rays*, p. 147. n. 917.
The Colours *of the Clouds*, ibid, 148. n. 920.
——— *of thin Plates*, p. 136. n. 887.
——— *their Properties*, ibid, and fol.
——— *of Bodies, from whence they proceed*, p. 144. n. 907. p. 146. n. 910.
Comets, (2.) p. 159. n. 979. and fol.
——— *their Motions explained*, (2.) p. 240. n. 1276. and fol.

The Conjunction *of the heavenly Bodies*, (2) p. 167. n. 1010.

Conſonances, (1.) *p.* 255. *n.* 525. and fol.

Courſe *of a River*, (1.) p. 195. n. 392. and fol.

How to Meaſure the Swiftneſs of its Courſe, p. 199. n. 399. and fol.

Rock Chryſtal *made lucid by rubbing*, (2.) p. 3. n. 552.

D

Natural Day, (2.) *p.* 193. *n.* 1141.

Artificial Day, *p.* 194. *n.* 1147.

Their Differences, ibid. n. 1152. and fol.

Lunar Day, *p.* *n.* 1394.

Declination *of a Star*, (2.) p. 182. n. 1079.

Degrees *of Latitude encreaſe as you come nearer the Poles*, (2.) p. n. 1374.

Denſity, (1.) *p.* 146. *n.* 284.

How to determine the Denſity *of Fluids*, (1.) p. 155. n. 309. and fol.

The Denſities *of Planets*, (2.) p. 231. n. 1260.

Dilatation by Heat : ſee Heat.

Ditonus, (1.) *p.* 255. *n.* 530.

Diviſibility *of Matter*, (1.) p. 4. n. 10. p. 5. n. 17. and fol. p. 10. n. 26.

Drop *becomes ſpherical*, (1.) p. 12. n. 33.

E

The Earth *ranked amongſt the Planets*, (2.) p. 155. n. 960.

—— *its Motion and Diſtance*, ibid. n. 960. p. 164. n. 996. and fol. p. 182. n. 1081. and fol. p. 200. n. 1183. and fol. p. 222. n. 1244. and fol. p. 242. n. 1281.

—— *its Dimenſions*, p. 158. n. 976.

—— *its Figure*, p. 264. n. 1360. and fol.

———— *it cannot be determin'd by Meaſures*, p. 269. n. 1375.

—— *its Elevation towards the Æquator determined*, p. 268. n. 1370.

—— *the Degrees on its Surface encreaſe as they draw nearer the Poles*, p. 269. n. 1374.

Point of the Eaſt, (2.) *p.* 187. *n.* 1102.
Echo, (1) *p.* 258. *n.* 542.
Eclipſe *of a Satellite*, (2.) p. 175. n. 1033.
—— *of the Moon* : ſee *Moon.*
—— *of the Sun*, ſee *Sun.*
Ecliptic *Line*, (2.) p. 165. n. *999.*
Plane of the Ecliptic, *p.* 153. *n.* 940.
Elaſticity, (1.) *p.* 17. *n.* 44.
Perfect Elaſticity, *p.* 76. *n.* 177.
The Law of Elaſticity, (1.) *p.* 123. *n.* 251.
The Elaſticity *of Fibres*, p. 120. n. 244. and fol.
The Elaſticity *of Plates of Metal*, p. 129. n. 262. and fo.
The Elaſticity *of a Ball*, p. 131. n. 266.
Elaſticity *from Heat* : ſee *Heat.*
Electricity, (2.) *p.* 3. *n.* 551.
———— *of a Glaſs-Tube*, ibid. n. 554. 555.
———— *of a Glaſs-Globe*, p. 5. n. 559. and fol.
Conjectures about the Cauſe of it, p. 7. n. 563. and fol.
The Elongation *of Planets*, (2.) p. 167. n. 1012.
The greateſt Elongation, *ibid. n.* 1013.
Excentricity *of Planets*, (2.) p. 152. n. 932.
Extenſion, (1.) *p.* 4. *n.* 8. *p.* 5. *n.* 13.
Deſcription of the Eye, (2.) *p.* 60. *n.* 712
Artificial Eye, (2.) *p.* 62.
Changes in the Eye, *p.* 63. *n.* 719. and fol.
The Defect of old Eyes *corrected*, p. 72. n. 756.
The Defect of ſhort ſighted Eyes *corrected*, p. 73. n. 758.

F

Fibres — their Elaſticity, (1.) p. 120. n. 244. and fol.
—— their Vibrations, *p.* 127. *n.* 257. and fol.
Properties of Fire, (2.) *p.* 1. *n.* 544. and fol.
Fire *contain'd in Bodies*, (2.) p. 3. n. 552. and fol.
The Action of Air upon Fire, (2.) *p.* 12. *n.* 577. *p.* 17. *n.* 593. *p.* 18. 594.
A Fifth, (1.) *p.* 255. *n.* 528.
Flame, (2) *p.* 15. *n.* 587. *p.* 17. *n.* 592.
Fluid, (1.) *p.* 11. *n.* 30.
Wherein Fluids *agree with Solids*, (1) p. 134. n. 270.

The Properties of Fluids, *p.* 135. *n.* 272. and fol.
The Action of Fluids *upon the Bottoms and Sides of Veſſels,* p. 138. n. 280.
The Motion of Fluids, (1.) *p.* 174. *n.* 354.
Fluids *ſpouting vertically,* p. 177. n. 358. and fol. See *Fountain.*
—— *Spouting obliquely,* p. 178. n. 360. and fol.
—— *Spouting out of Veſſels,* p. 188. n. 378. and fol.
Compariſon of the Times in which Veſſels become empty, p. 189. n. 379. and fol.
Solids immers'd in Fluids, *p.* 147. *n.* 290. and fol.
—— *heavier,* p. 148. n. 292. p. 149. n. 296. and fol.
—— *lighter,* p. 154. n. 306. and fol.
Fluidity, *from whence it ariſes,* (1.) p. 133. n. 269.
—— *whether it depends upon Heat?* (2.) p. 20. n. 603.
Full Moon, (2.) *p.* 175. *n.* 1043.
Focus, (2.) *p.* 40. *n.* 650.
Fountain *of Hero,* (1.) p. 237. n. 474.
—— —— *from the Compreſſion of the Air,* p. 231. n. 459.
Two little Fountains, *p.* 230. *n.* 457. *p.* 230. *n.* 458.
A Fourth, (1.) *p.* 255. *n.* 529.

G.

Glaſs *appears lucid by Attrition,* (2.) p. 3. n. 553. p. 5. n. 557.
Burning Glaſſes, (2.) *p.* 56. *n.* 703.
Gravity, (1.) *p.* 25. *n.* 73. (2.) *p.* 296. *n.* 1206. and fol.
The Phænomena of Gravity, (1.) *p.* 25. *n.* 72. *p.* 25. *n.* 75, 77.
Reſpective Gravity, (1.) *p.* 149. *n.* 295.
Specific Gravity, (1.) *p.* 146. *n.* 287.
Gravity *univerſal,* (2.) p. 206. n. 1206.
The Laws of Gravity, *ibid. n.* 1207, 1208.
Gravity *is prov'd,* p. 207. n. 1211. and fol.
Propoſitions relating to Gravity, *p.* 213. *n.* 1226. and fol.
Gravity *not to be aſcrib'd to any Impreſſion known to us,* p. 316. n. 1238.
Gravity *upon the Surfaces of Planets,* p. 231. n. 1258.

H

Hard Bodies, (1.) *p.* 11. *n.* 28.
Heat, (2.) *p.* 14. *n.* 579, 580, 584.
Heat *is not in proportion to the Fire*, p. 15. n. 588.
Heat *makes Bodies emit Light or ſhine*, p. 16. n. 591.
—— *dilates Bodies*, p. 18. n. 596, 597.
—— *melts ſome Bodies*, p. 20. n. 602.
—— *gives Elaſticity to ſome Bodies*, ibid. n. 605.
—— *What Sorts of Bodies grow ſooneſt warm*, p. 145. n. 908.
Heavens —*what they are*, (2.) p. 161. n. 986.
—— *why blue*, p. 162. n. 987.
Heavy *Bodies do not tend towards the Center of the Earth*, (2.) p. 368. n. 1371.
Heterogeneous *Body*, (1.) p. 146. n. 286.
Heterogeneous *Rays*, (2.) p. 109. n. 850.
Homogeneous *Body*, (1.) p. 146. n. 285.
Homogeneous *Rays*, (2.) p. 108. n. 849.
Horizon, (2.) p. 185. n. 1096.

I

Glaſs Images *going up and down in Water*, (1.) p. 231. n. 462.
Inclin'd *Plane*, (1.) p. 56. n. 139.
The Inertia *of a Body*, (1.) p. 5. n. 12.
Iris *or Rainbow when produc'd*, (2.) p. 134. n. 884, 885.
Two frequently appear at a Time, p. 136. n. 886.
Explanation of the Motion of Light in forming a Rainbow, p. 127. n. 875. and fol.
Judgment *concerning the Diſtance and Magnitude of Objects*: ſee *Light*.
—— *concerning the Magnitude of the Sun and Moon near the Horizon*, (2.) p. 67. n. 735.
Jupiter, (2.) *p.* 156. *n.* 962.
—— *its Weight*, p. 231. n. 1255.
—— *Gravity on its Surface*, p. ibid. n. 1258.
—— *its Denſity*, p. ibid. n. 1260.
—— *its Force acting on Saturn*, p. 236. n. 1270.
—— *on Mars*, p. 238. n. 1273.
—— *its Figure*, p. 265. n. 1363.

L

Deſcription and uſe of the Magic Lantern, (2.) *p.* 99. *n.* 837. and fol.

Perfection of a magic Lantern, (2.) *p.* 102. *n.* 839.

Latitude *of an heavenly Body*, (2.) p. 166. n. 1006.

—— *of a Place*, p. 189. n. 1118.

Circle of Latitude, *p. ibid. n.* 1119.

Law *of Nature*, (1.) p. 2. n. 4.

How the Laws *of Nature are diſcover'd*, ibid.

Glaſs Lens, (2.) 53. *n.* 692.

The Properties of Lenſes, (2.) *p.* 54. *n.* 966.

Convex Lenſes, *p.* 55. *n.* 698. and fol.

Concave Lenſes, *p.* 57. *n.* 704. and fol.

Multiplying Lenſes, *p.* 73. *n.* 759.

Lever, (1.) *p.* 35. *n.* 103, 104.

—— *its Properties*, p. 35. n. 105. and fol.

Light, (2.) *p.* 14. *n.* 581. and fol.

Bodies receive Light *from Heat* : ſee *Heat*.

A Ray of Light : *ſee Ray*.

The Motion of Light, (2.) *p.* 16. *n.* 589, 590.

The Celerity of Light *in different Mediums*, p. 37. n. 640.

Inflexion of Light, *p.* 24. *n.* 611. and fol.

—— *its Refraction*: ſee *Refraction*.

—— *its Reflection* : ſee *Reflection*.

Bodies liquefied : ſee *Heat*.

Longitude *of an heavenly Body*, (2) p. 166. n. 1003, 1004.

Longitude *of a Place*, p. 189. n. 1121.

M

Simple Machines, (1.) *p.* 35. *n.* 103. *p.* 38. *n.* 112. *p.* 40. *n.* 115. *p.* 44. *n.* 119. *p.* 45. *n.* 121.

Compound Machines, *p.* 47. *n.* 122. and fol.

A Machine *by which the Properties of the Wedge are demonſtrated*, (1.) p. 44. n. 120.

A Machine *to determine the Acceleration of falling Bodies*, p. 53. n. 132.

A Machine *to demonſtrate the Properties of an inclin'd Plane*, (1.) p. 57. n. 143.

——— *for making Experiments concerning Percuſſion*, p. 68. n. 170.

——— *for making Experiments concerning compound Motion, and oblique Percuſſion*, p. 86. n. 191.

——— *for oblique Powers*, p. 92. n. 197. p. 95. n. 203, 204.

——— *for the Projection of heavy Bodies*, (1.) p. 100. n. 210.

——— *to ſhew the Central Forces*, p. 105. n. 222.

——— *for making Experiments concerning Elaſticity*, p. 122. n. 249.

——— *to ſhew the Preſſure of Fluids*, p. 139. n. 281. p. 142. n. 282. p. 144. n. 283.

——— *to find out the Denſity of Fluids*, p. 156. n. 312. p. 158. n. 314.

——— *to compare the Denſities of Solids*, p. 159. n. 317. n. 318.

——— *to make Experiments concerning the Reſiſtance of Fluids*, p. 170. n. 346.

——— *to make Experiments concerning Fluids ſpouting out*, p. 175. n. 356. p. 182. n. 370.

——— *to meaſure the Celerity of a River*, p. 198. n. 398.

Machine *to let Bodies down into the Air Pump, when the Receiver is void of Air*, p. 26. n. 77.

——— *to whirl Bodies round in a Vacuum*, (2.) p. n. 567.

——— *to make Experiments in condenſed Air*, (1.) p. 228. n. 454.

——— *uſed by Divers*, p. 231. n. 461.

Various Machines, *the Effect of which depends upon the Action of the Air*, (1.) p. 233. n. 467. and fol.

——— *to whirl round a Glaſs Globe*, (2.) p. 4. n. 556.

——— *to ſhew the Inflection of Light*, p. 24. n. 611.

——— *that ſhew the Refraction of Light*, p. 29. n. 630. p. 38. *in the beginning*, p. 49. p. 55. n. 702. p. 58. n. 708.

Apparent Magnitude: ſee *Judgment and Sight.*

Mars, (2.) *p.* 155. *n.* 961.
The cœleſtial Matter *very ſubtile,* (2.) p. 221. n. 1243.
——— *it does not move Bodies,* p. 222. n. 1244.
The Quantities of Matter *in Planets,* (2) p. 231. n. 1255.
The Medium *of Light,* (1.) p. 7. n. 15.
Mercury *ſhines in a Vacunm,* (2.) p. 11. n. 571. and f.
The Planet Mercury, (2.) *p.* 155. *n.* 958.
Meridians, (2.) *p.* 181. *n.* 1077. *p.* 188. *n.* 1114, 1116.
Firſt Meridian, *p.* 189. *n.* 1120.
Meridian *Line,* (2.) p. 186. n. 1101.
Microſcope, (2.) *p.* 74. *n.* 760.
——— *it magnifies ſmall Objects,* ibid. n. 761.
——— *it magnifies more when compounded,* p. 76. n. 765.
Milky *Way,* p. 284. n. 1199.
——— *it is an Aſſemblage of Stars,* p. ibid. n. 1200.
Mirrours *or Looking Glaſſes plane,* (2.) p. 87. n. 799. and fol.
——— *ſpherical and convex,* p. 89. n. 806. and fol.
——— *ſpherical and concave,* p. 90. n. 813. and fol.
——— *burning,* p. 91. n. 814.
——— *cylindric and conic,* p. 117. n. 863.
The Phænomena of the Moon, (2.) *p.* 174. *n.* 1035. and fol.
Why it appears bigger near the Horizon, p. 67. n. 735.
It turns round its Axis, p. 157. n. 970. p. 184. n. 1092.
It always turns the ſame Face towards the Earth, p. 184. n. 1092.
Eclipſe of the Moon, (2.) *p.* 176. *n.* 1047.
——— *when it happens,* ibid. n. 1049. 1051.
——— *Partial,* p. 177. n. 1052.
——— *Total,* ibid. n. 1053.
——— *Central,* ibid. n. 1054.
The Gravity of the Moon *towards the Earth,* p. 211. n. 1225.

The Denſity of the Moon, *p. n.* 1427.
The Gravity of the Moon *in its Surface*, p. n. 1429.
The Weight of the Moon, *p. n.* 1429.
The Figure of the Moon, *p. n.* 1431.
A Phyſical Explanation of the Motion of the Moon, *p.* 243. n. 1285. *and* fol.
The Motion and Diſtance of the Moon. (2.) *p.* 157. n. 967. *and* fol.
The Dimenſions of the Moon, *p.* 159. n. 977.
The Diſtance of the Moon, *if in its periodical Time it was carried round the Earth, and the Earth ſtood ſtill*, p. 228. n. 1253.
The Determination of the Forces that diſturb the Moon, *p.* 245. *n.* 1291. *p.* 247. *n.* 1296. *p.* 251. *n.* 1306, 1307. *p. n.* 1336.
The Motion of the Apſides of the Moon, *p.* 157. *n.* 970. *p.* 256. *n.* 1325.
The Motion of the Nodes of the Moon, *p.* 157. *n.* 970. *p. n.* 1341. *and* fol.
The Change of the Moon's *Excentricity*, p. 157. n. 968. p. n. 1328, 1329.
The Change of the Inclination of the Moon's *Orbit*, p. 157. n. 969. p. n. 1345. *and* fol.
A Periodical Lunar Month, (2.) *p.* 175. *n.* 1037.
———— *Synodical* Month, *p. ibid. n.* 1038.
——*Body moveable or ſuſceptible of* Motion, (1.) *p.* 4. n. 11.
Motion, (1.) *p.* 19. *n.* 47.
————*its Quantity*, p. 20. n. 54.
————*its Direction*, p. 21. n. 55.
————*its Laws*, p. 49. n. 124. *and* fol.
The comparing of Motions, (1.) *p.* 22. n. 62. *and* fol.
Accelerated Motion, (1.) *p.* 51. *n.* 127.
Motion *retarded*, p. 52. n. 128.
————*compounded*, p. 85. n. 190. *and* fol.
———— ————p. 88. n. 192.
————*Relative*, (2.) p. 161. n. 985.

———*Apparent* ibid. n. 985. p. 163. n. 992. *and* fol.
———*in Conſequentia*, p. 153. n. 946.
———*in Antecedentia*, p. 154. n. 947.
———*diurnal*, p. 181. n. 1074. n. 182. n. 1081. *and* fol.
———*of Fluids.* (1.) p. 174. n. 354. *and* fol.
———*of Light.* See *Light.*
———*its Quantity in the World not always the ſame*, (1.) p. n. 187, 188.

N

Nadir, (2.) *p.* 186. *n.* 1100.
The Nodes *of the Planets*, (2.) p. 153. n. 941.
The Line of Nodes, *p. ibid. n.* 942.
New Moon, (2.) 175. n. 1042.
Two Nubeculæ *in the Heavens*, (2.) p. 204. n. 1201.

O

Opaque *Body*, (2.) p. 58. n. 709.
Opacity *depends upon the Pores*, (2.) p. 105. n. 843.
Octave, (1.) *p.* *n.* 527.
Oppoſition *of Cæleſtial Bodies*, (2.) *p.* 167. n. 1011.

P

Parallax of the Stars, (2.) p. 187. n. 1106. *and* fol.
———*annual*, p. 282. n. 1187, 1188.
Subtility of Parts, (1.) *p.* 9. n. 20.
Pendulum, (1.) *p.* 61. n. 153.
———*compound*, p. 65. n. 161.
Motion of Pendulums, *p.* 61. n. 154. *and* fol.
Penumbra (2.) *p.* 179. n, 1060.
Percuſſion *direct*, (1.) p. 67. n. 166.
———*of Bodies not elaſtic*, p. 72. n. 171. *and* fol.
———*of elaſtic Bodies*, p. 77. n. 179. *and* fol.
———*oblique*, p. 89. n. 193. *and* fol.
Perihelia *of Planets.*
Natural Phænomena, (1.) *p.* 2. *n.* 2.
Phoſphorus *of Urine*, (2.) p. 12. n. 575.
———*in a Vacuum*, (2.) p. 18. n. 595.
Natural Philoſophy, (1.) *p.* 2. *n.* 3.
Place, (1.) *p.* 19. *n.* 48, 49, 50.
Plaſter *ſhines in a Vacuum*, (2.) p. 10. n. 570.
Planets, (2.) *p.* 151. *n.* 926.

——*Pris*

———*Primary*, p. 151, n. 927.
———*Secondary*, ibid. n. 928.
———*Inferior*, p. 156. n. 964.
———*Superior*, *ibid.*
The Appearances of Inferior Planets, *p.* 168. *n.* 1015. *and* fol.
The Appearances of Superior Planets, *p.* 171. *n.* 1024. *and* fol.
———*Their Figures determin'd*, p. n. 1360.
———*their Diſtances*, p. 155. n. 956. *and* fol.
———*their Dimenſions*, p. 158. n. 975. p. 231. n. 1256.
———*their Weights*, p. *ibid.* n. 1255.
———*their Denſities*, p. *ibid.* n. 1260.
———*their Motions*, p. 151. n. 929 *and* fol.
———*the Effects of their mutual Actions*, p. 235. n. 1274.
———*they revolve about the Center of Gravity of the whole Syſtem*, p. 234. n. 1264.
———*their Orbits are at reſt*, *ibid.* n. 1265.
———*their Motions explain'd according to the Principles of Natural Philoſophy*, p. 235. n. 1275.
Motions and the Diſtances of the Secondary Planets, *p.* 156. *n.* 965. *and* fol. *p.* 191. *n.* 1130. *and* fol.
———*an Explanation of theſe Motions*, p. 240. n.. 1277. *and* fol.
The Points *of Reſt in Strings in Motion*, (1.) p. 257. *n.* 538, 539.
The Poles *of a Planet*, (2.) p. 154. n. 953.
———*of the World.*
———*Arctic*, p. 184. n. 1090.
———*Antarctic*, *ibid.* n. 1091.
———*of the Ecliptic*, p. 166. n. 1007.
The Polar *Circles*, p. 184. n. 1091. p. 188. n. 1114.
Power (1.) *p.* 21. *n.* 56.
———*its Intenſity*, p. 21. n. 57.
The Actions of Powers *compared*, p. 24, n. 67. *and* fol.
The Actions of oblique Powers *determin'd*, p. 91. n. 196, *and* fol.
The Præceſſion *of the Æquinoxes. See Æquinox.*

The Projection *of heavy Bodies*, (1.) p, 99. n. 208. *and* fol.
Pulley, (1.) *p.* 27. *n.* 82, 83. *p.* 40. *n.* 115. *and* fol.
Common Pumps, (1.) *p.* 236. *n.* 472.

R

Radiant *Point*, (2.) p. 40. n. 645.
Rainbow. *See* Iris.
Ray *of Light*, (2.) p. 23. n. 610.
———*diverging*, (2.) p. 39. n. 643.
———*converging*, p. 40. n. 648.
———*incident*, p. 28. n. 620.
———*refracted*, *ibid.* n. 622.
———*reflected*, p. 81. n. 780.
———*homogeneous*, p. 108. n. 849.
———*heterogeneous*, ibid. *n.* 850.
———*they move in Curve Lines in the Air*, p. 178. n. 1056.
Reflexion *of Light from Bodies*, (2.) p. 58. n. 710.
———*from a poliſh'd Surface*, (2.) p. 81. n. 779.
———*its Laws*, *ibid.* n. 783. *and* fol.
———*it has a great Relation with Refraction*, p. 86. n. 795. *and* fol.
Black Bodies reflect *no Light*, p. 107. n. 845.
Refraction *of Light*, (2.) p. 26. n. 616.
———*when cauſed*, *ibid.* n. 617.
———*whence it ariſes*, ibid. *n.* 618.
———*its Laws*, p. 28. n. 624. *and* fol.
A conſtant Proportion between the Sine of Incidence and the Sine of Refraction, *p.* 37. *n.* 639.
The Cauſe of this Effect, p. 31. n. 633. *and* fol.
The Laws of Refraction *in Mediums divided by a plane Surface*, p. 39. n. 643. *in Mediums divided by a ſpherical Surface*, p. 44. n. 660.
Refraction *of the Stars*, p. 188. n. 1110 *and* fol.
Refrangibility *different in different Rays*, (2.) p. 108. n. 847.
———*conſtantly the ſame in ſingle Rays*, p. 115. n. 855.
———*the greater it is, the more eaſily are Rays reflected*, p. 122. n. 868.

Repul-

Repulſion, (1.) *p.* 15. *n.* 40. *and* fol.
Reſiſtance *of Fluids,* (1.) *p.* 162. n. 319. *and* fol.
Retardation *of Bodies aſcending vertically,* (1.) p. 55 n. 135.
—— *Aſcending upon an inclin'd Plane,* p. 60. n. 151. *and* fol.
—— *of Bodies moving in Fluids,* (1.) p. 165. n. 329.
Retardation *of a Pendulum in a Fluid,* p. 171. n. 347. *and* fol.
—— *of a Body riſing upwards,* p. 172. n. 351. *and* fol.
Retardations *compar'd with one another,* p. 165. n. 331. *and* fol.
—— *compared with Gravity,* p. 166. n. 336.
Ring *of Saturn,* (2.) p. 156. n. 963. p. 174. n. 1034.
Riſing *of the Stars,* (2.) p. 186. n. 1097.
River, (1.) *p.* 195. n. 390.
—— *its Section,* p. 195. n. 391.
—— *its Courſe,* p. 195. n. 392. *and* fol.
Rules *for reaſoning in Philoſophy,* (1.) p. 3. n. 5, 6, 7.

S

Satellites. See *Secondary Planets.*
Saturn, (2.) *p.* 156. *n.* 963.
—— *its Weight,* p. 231. n. 1255.
—— *Gravity on its Surface, ibid.* n. 1258.
—— *its Denſity, ibid.* n. 1260.
—— *the Force with which it acts on Jupiter,* p. 238. n. 1272.
An inſide Screw, (1.) p. 45. n. 121.
An outſide Screw, *ibid.*
The Uſe of both, ibid.
An endleſs Screw, (1.) *p.* 47. n. 123.
Seaſons *of the Year,* p. 199. n. 1176. *and* fol.
Sky-Rocket, *p.* 22. *n.* 609.
—— *in the torrid Zone, ibid.* n. 1179. *and* fol.
Seſquiditonus, (1.) *p.* 255. *n.* 531.
The Setting *of the Stars,* (2.) p. 183. n. 1089.
Signs *of the Zodiac.* See Zodiac.
Smoak, (2.) *p* 15 *n.* 587. *p.* 17. *n.* 592.
Soft *Body,* (1.) p. 11. n. 29.

The Sun *agitated by a ſmall Motion,* (2.) p. 155. n. 957. p. 235. n. 1266.
——*the Effects of its Motion,* p. 235. n. 1267.
——*turns round its Axis,* p. 155. n. 957. p. 180. n. 1071.
——*ſeems to be mov'd by the Motion of the Earth,* p. 164. *n.* 996. *and* fol.
——*why it appears larger near the Horizon,* p. 67. n. 735.
Eclipſe of the Sun, *p.* 176. *n.* 1046.
——*different in different Places,* p. 179. n. 1065.
——*when it happens,* p. 118. n. 1059.
——*partial,* p. 180. n. 1067, 1068.
——*total,* p. 179. n. 1067, 1068.
——*central,* p. 180. n. 1068.
——*annular, ibid.* n. 1070.
The Weight of the Sun, p. 231. n. 1255.
——*Gravity on its Surface, ibid.* n. 1258.
——*its Denſity,* p. *ibid.* n. 1260.
Solidity *of Matter,* (1.) p. 4. n. 9.
Solſtices, (2.) p. 195. n. 1155.
Sound *depends upon the Air,* (1.) p. 249. n. 504.
——*its Intenſity,* p. 253. n. 515. *and* fol.
——*it is augmented in Air compreſs'd,* p. 253. n. 516.
——*its Celerity,* p. 251. n. 508. *and* foll.
Space. See *Vacuum.*
Sphere, *parallel,* (2.) *p.* 190. n. 1123, 1124.
——*oblique,* p. *ibid.* n. 1125. *and* fol.
——*right,* p. 192. n. 1138, *and* fol.
——*Fix'd* Stars, (2.) *p.* 150. *n.* 923. p. 202. n. 1190. *and* fol.
——*found to be very numerous by the Help of Teleſcopes,* p. 204. n. 1202.
——*ſome of them periodical,* p. 204. n. 1203.
——*ſome of them have appear'd, and then totally diſappear'd, ibid.* n. 1204.
White Spots *in the Heavens,* (2.). p. 204. n. 1205.
The Conſonances of Strings, (1.) *p.* 256. *n.* 532. *and* fol.

The Motion of ſome Strings *communicated to others*, p. 256. n. 536. *and* fol.
Syphon, (1.) *p.* 233. *n.* 467, 469. *p.* 234. n. 470.
Points of Suſpenſion, (1.) *p.* 28. n. 86.
Planetary Syſtem, (2.) *p.* 150. *n.* 922.
——*an Explanation of it according to the Principles of Natural Philoſophy*, (2.) p. 235. n. 1275.
Syzygies, (2.) *p.* 176. n. 1044.
T
Teleſcope, (2.) p. 76. n. 768.
——*Aſtronomical*, ibid. *n.* 769.
——*proper to view terreſtrial Objects*, p. 77. n. 772. p. 77. n. 776.
——*why they are not more perfect*, p. 122. n. 867.
Thermometer, (2.) *p.* 19. *n.* 598, 599.
Natural Things, (1.) *p.* 1. *n.* 1.
Tide, (2.) *p.* 274. n. 1395. *and* fol.
——*derived from the Influence of the Sun and Moon*, p. n. 1390. *and* fol.
The Forces of Influences determined, p. 273. n. 1416. *and* f.
Time, (1.) *p.* 20. *n.* 51, 52.
Mean Time, (2.) *p.* 194. n. 1145.
Tone (1.) *p.* 255. *n.* 522.
——*grave*, ibid.
——*acute*, ibid.
Tropics, (2.) *p.* 183. *n.* 1089. *p.* 188. *n.* 1114.
Tubes *fill'd with Gun-powder*, (2.) p. 22. n. 609.
Tranſparent *Body*, (2.) p. 104. n. 840.
The Parts of all Bodies tranſparent, *ibid.* n. 841.
Tranſparent *Bodies become opaque upon the Separation of their Parts*, p. 106. n. 844.
Speaking Trumpet, (1.) p. 258. n. 543.
Twilights, (2.) *p.* 194. *n.* 1149. *and* fol.
V
A Vacuum *is poſſible*, (1.) p. 5. n. 13.
——*its Properties*, (1.) p. 7. n. 15.
——*its real Exiſtence in Nature*, (2.) p. 217. n. 1239. *and* fol.

Velocity, (1.) *p.* 20. *n.* 53.
Venus, (2.) *p.* 155. n. 959.
——*it is an Aſſemblage of Stars,* p. 204. n. 1200.
Vibrations *of Pendulums.* See *Pendulums.*
——*of Fibres.* See *Fibres.*
Viſion, (2.) *p.* 62. *n.* 716.
Diſtinct Viſion, *p.* 63. *n.* 717. *p.* 64. *n.* 724. *p.* 65. *n.* 728.
Confuſed Viſion, *p.* 63. *n.* 718.
Judgment concerning the Diſtance of Objects ſeen, p. 66. n. 729. *and* fol.
Apparent Magnitude, p. 66. n. 733.
Judgment concerning the Magnitude, ibid. *n.* 734.
Viſion *thro' a plane Glaſs,* (2.) p. 68. n. 739. *and* fol.
——*thro' a convex Lens,* (2.) p. 69. n. 745. *and* fol.
——*thro' a concave Lens,* (2.) p. 72. n. 757.
——*Objects appear magnified in Water,* (2.) p. 69. n. 744.

W

Wave *on the Surface of a Fluid,* (1.) p. 201. n. 402. p. 202. n. 405.
——*Breadth of it,* p. 202. n. 404.
——*Motion and Reflexion of it,* &c. *p.* 201. *n.* 402. *p.* 202. *n.* 405.
——*Celerity of them,* p. 208. n. 416.
Wave *in Air,* p. 239. n. 476.
——*Motion of them and Celerity,* &c. p. 240. n. 477. *and* fol.
Water *is melted Ice,* (2.) p. 20. n. 604.
Wedge, (1.) *p.* 43. *n.* 118, 119.
Point of the Weſt, (2.) p. 187. n. 1103.
Wheels *with Teeth,* (1.) p. 39. n. 114.
Whiteneſs, (2.) *p.* 124. *n.* 870.
——*reſulting from a Mixture of Colours,* ibid. *n.* 871. *and* 872.
A white Body *grows warm ſooner than other colour'd Bodies,* p. 145. n. 909
Shining Wood, (2.) *p.* 13. n. 578.

Z

Zenith, (2.) *p.* 186. *n.* 1099.
Zodiac, (2.) *p.* 166. *n.* 1008, 1009.
——*its Signs*, p. 165. n. 999. p. 202. n. 1191, 1192.
Zones, (2.) p. 196. n. 1159. *and* fol.
——*Phænomena of the Frigid* Zones, *p.* 196. *n.* 1165, p. 197, n. 1170. *and* fol. *p.* 199. n. 1176. *and* fol.
——*of the Temperate ones*, p. 196. n. 1165. *and* fol. *p.* 199. n. 1176. *and* fol.
——*Torrid* Zones, *p.* 196. *n.* 1163, 1167. *p.* 199. *n.* 1179, *and* fol.

FINIS.

ERRATA and ADDITIONS

FOR THE

Firſt VOLUME.

IN the Dedication, Page 3. l. 2. *read* tho' ſome. In the Preface, p. viij. l. 7 dele *with a wonderful regularity*, p. ix. l. 5 and 6. r. *have our Deductions to be juſt, but our Notions muſt agree with the Things about which we reaſon*, p. xv. l. 19. r. *appears to be certain.*

Page 2. for may always be, r. is. p. 5. l. 19. *dele* conſequently. p. 5. l. 21, 22, 23. r. that there might be an infinite Body, and ſuch a Body wou'd have no Figure. p. 7. l. 12. r. But that. l. 14. r. and as it is finite. p. 8. l. 34. r. They attribute the Properties. p. 11. l. 20. r. the cloſer that Coheſion is, the nearer a Body approaches. p. 14. l. 15. *dele* likewiſe. p. 22. l. 12. r. in unequal. p. 25. l. 19 after *Time.* r. *every where* p. 30. l. 19. r. unequal Parts. p. 32. l. 16. r. *Plate* III. *Fig.* 3. p. 43. l. 5. r. but theſe l 6. the only uſes of Mechanics. l. 7. *dele* are not confin'd only to theſe Methods. p. 44. l. 19. r. and have. p. 54. l. 29. *after* of the others, *add*, It is very hard to make this periment exactly, becauſe the Body M in its fall, does not exactly ſtrike the ſame Point of the Brachium B every Time. But by the following Method there never happens any ſenſible Error. Let there be a ſmall Hole at the End of the *Brachium* B; in which Hole muſt be faſten'd a ſmall Cord, of the Length of three or four Feet at leaſt, hanging down below the Machine, and ſuſtraining a Braſs or Leaden Ball of about two Ounces. If this Ball be rais'd to different Heights, and then let fall ſo as to move the Balance by the Pull that it will give, the Squares of the Weight rais'd by the oppoſite End of the Beam, will be exactly as the Heights from whence the Ball is let fall. By this Method, one may eaſily (without any Error) determine the Height from which the Ball is let fall, and the ſtroke will thus always exactly act upon the ſame Point of the *Brachium* B, and by reaſon of the Length of the String never be ſenſibly oblique. p. 64. l. 18. r. of a Pendulum. p. 68. l. 29. r. Pipe of Braſs. p. 71. l. 17, and 18. r. Oil, and all the Parts muſt be join'd. l. 19. r. the Ring, then put in the Clay, and take them. p. 91. l. 6. r. Diagonal *a q*. p. 108. lin. penult. *after* the Ball, *add*, in the Part I F of the Trough where the Ball L is not, that is at F upon the Table A, near G a flat piece of Wood muſt hang, making a right Angle with the Sides of the Trough, and moving very freely about its upper Side by help of a Braſs Wire going thro' it. At F, on one of the Sides of the Trough within, is fix'd a wooden Spring made faſt there, but looſe at G, towards which it goes; ſo that this looſe Fnd of the Spring may be retain'd in a vertical Slit or Grove, made in the little flat Board above-mention'd; but it muſt ſtick in it but very little, and therefore the Spring muſt be cut narrow at that End. A String muſt be fix'd to the hanging Board, and be ſo join'd to the String G L, that the Ball L may not recede from the Center, and raiſe the Weight in the Foot of the Table, without pulling the above-mention'd vertical Board forwards, and letting looſe the Spring which will then ſtrike againſt the Side of the Trough, ſo that the Blow may be heard. The ſame muſt be ſaid of the Trough on the Table B: As for ſome few other Alterations made ſince in the Machine, I ſhall take no Notice of them. p. 112. l. 14. r. Forces, that Time may be conſider'd as the Velocity. p. 116. l. 10. r. of this. l. 11. r. of that. l. penult. r. put a Ball. p. 127. l. 31. r. the Motions of Cords with the Motions. p. 128. l. 6. r. Vibrations are. p. 135. l. 2. *dele* no. p. 136. l. 15, and 16. *dele* or loweſt. p. 139. l. 13. *dele* from. p. 140. l. 9. r. Plate B. p. 150. l. 8. r. loſe unequal. p. 153. l. 2 . r. immerſed in Water. p. 154. l. 2. dele the. p. 162. l. 15. r. the Reſiſtance from. p. 165. l. 25. r. Quantities of Matter. p. 167. l. 17. r. deſcrib'd by the Aſcent of a. p. 169. l. 23. r. Points (keeping the ſame Proportion.). p. 173. l. 23. r. inſtead of *in Vacuo* r. in a Medium of the ſame Denſity not reſiſting, if there cou'd be ſuch a Medium. l. ult. after *in Vacuo*, add, The Heights to which a Body wou'd aſcend, with the fame Velocity, in a Vacuum and in a Medium not reſiſting, are to one another inverſely, as the Gravities of the Body in Vacuo, and in ſuch a Medium; but this is the reſpective Gravity of the Body. The Truth of this Propoſition appears by comparing the Numbers 137, 45, 142, 149. p. 174. l. 22, and 23 r. the whole Effect of the Preſſure. p. 180. l. 3, and 4 r. there is alſo to be obſerv'd another Action of the Air. p. 182. l. 15, and 16. r. an half long, eight or 10 Inches broad. p. 187. l. 17. r. the Times. p. 188. l. 4. r. G is leſs diſtant from the Surface of the Water. l. 5, and 6. r. inſtead of the Surface of the Water r. it. p. 198. l. 17. r. of the Square Roots. p. 193. l. 3. r. till this has loſt all its Motion. p. 194. l. 10. r. The Veſſels A, E and p. 205. l. 19.

r. Leg G H. p 210. l. 14. r. cannot be preſs'd. p. 211. l. 12. r. half a quarter. l. 23. r. in that manner; which Preſſure preſerves them. p. 215. l. 15. r. leſs compreſs'd. p. 216. l. 20. r. 2000 times. l. 56. r. between the Centers of the Particles is diminiſh'd. p. 217. l. 28. r. increas'd in the Ratio. l. 29. r. Diſtance between the. p. 221. l 12. r. Glaſſes to be exhauſted, are ſet. l. 15. r. which is. p. 225. l. 29. r. D C. p. 335. l. 30. r. ſuſtains. p. 237 l. 15. r. the Veſſel A B. p. 242. l. 28. r. tho' Elaſticity acts. p. 243. l. 32. r. from the Middle Point of the Space. p. 246. l. 4. r. the Ratio compounded of theſe l. 5. *dele* compounded, p. 249 l. 19. r. Wire *b d*. p. 252. l. 14. r. 1080 *French* Feet. p. 253. l. 21. r. is directly. l. 22. *after* coming *add*, *and inverſly as the Breadth of the Wave*. p. 259. At the End, *add*, and the great End thro' which the Sound goes out, muſt be ſpread out round to carry the Sound every way.

ERRATA in the Numbers in the Margin, which mark Propoſitions, or refer to them.

Page 20. againſt line 17. read N° 52. p. 31. l. 24. r. (94.) p. 32. l. 2. r. (95.) l. 5. r. (96.) l. 8. r. (97.) inſtead of 98. l. 13. r. (98.) p. 44. l. 5. inſert (*70.) referring to the Word *Height* *. p. 58. l. 19. r. (146.) p. 83. l. *antepen.* for (* 120.) r. (* 126.) p. 100. l. 14. r. (210.) p. 103. l. ult. r. (* 138) referring to the Word *Celerities* *. p. 104. l. 18. r. (217.) p. 112. l. 12. *dele* (231.) and write it 3 Lines lower. p. 134. l. 27. *dele* (272.) p. 147. l. 13. r. (290) l. 32. r. (291.) p. 154. l 2. r. (306.) l. 7. r. (307.) p. 167. l. 30. for (*159.) r. (*156.) p. 171. l. 26. for (247.) r. (347.) p. 172. l. 3. r. (349) p. 220. l. 28. r. (435.) p. 240 l. 8. for (703) r. (403.) p. 246. l. 2. for (* 480.) r. (* 489.) p. 247. l. 29. r. (* 434.) referring to the Word *Cold*. * p. 249. l. 14. r. (504.) p. 250. l. 31. for (* 215) r. (257) p. 252. l. 20. for (499) r. (442.) p. 253. l. 13. r. (514.) p. 254 l. 33. for (* 116) r. (* 516.) p. 258. l. 34. for (541) r. (543.

ERRATA in the PLATES.

P*L.* II. *Fig.* 6. under Number (9). there ſhou'd hang two Weights inſtead of one. *Pl.* III. *Fig.* 7. In the middle between A and B put in the Letter C. *Pl.* IV. *Fig.* 4. The Weight P muſt be mark'd with Number (7). *Pl.* 5. *Fig.* 5. the little Weight muſt be mark'd M. *Pl.* VI. *Fig.* 2. the Weight 6 muſt be mark'd P, and the Weight (1) M. *Fig.* 3. the Rope ſhou'd be brought over the loweſt of the upper Pulleys to the Top of the Box of the lower Pulleys. *Fig.* 7. The Ends of the ſcrew'd Wire that goes thro' F F, muſt be mark'd *g g*, and the two Pullies muſt be mark'd *d d*, *Fig.* 9. The End of the Handle muſt be mark'd D. *Pl.* 7. *Fig.* 7. The Pulley mark'd C ſhou'd be mark'd G. *Fig.* 9. The String that goes to P ſhou'd come on the Inſide of the Pins. *Pl.* 8. *Fig.* 2. The Letter D ſhou'd be at the Ball between P and B. *Pl.* 9. *Fig.* 7. The Pins *p*, *p*, *p*, *p*, ſhou'd have Holes at their Ends. *Pl.* 14. *Fig.* 3. The Weight P ſhou'd be mark'd (2.) *Pl.* 27. *Fig.* 1. The ſmall Tube *g* C ſhou'd have *e* at Top.

BOOKS *Printed for, and Sold by* W. TAYLOR, *at the* Ship *and* Black Swan, *in* Pater-Noſter-Row.

ANNALS of K. George, in 5 Vol.	8*vo.*
Adventures of Telemachus in Engliſh by *Boyer*,	12*o.*
——with Cuts, by Ozel. 2 Vol.	12*mo.*
——Of Capt. Falkner,	8*vo.*
——Of Theagenes and Chariclea, done from the Greek of Heliodorus,	12*mo.*
Aſhmole's Hiſtory of the Garter abridged,	8*vo.*
Arwaker's Fables,	8*vo.*
Art of Thinking,	12*mo.*
Art of Self-Government,	8*vo.*
Art of Speaking,	12*mo.*
Art of Painting, by Freſnoy,	8*vo.*
Academy of Complements.	12*mo.*
Arianiſme confuted, by C. Place. M. A.	8*vo.*
Antiquities of York,	8*vo.*
Advice to a Son, directing him how to demean himſelf in the moſt important Paſſages of his Life,	12*mo.*
Abridgment of the Statutes, 5 Vol.	8*vo.*
Addiſon's Travels to Italy,	12*mo.*
——His Notes on Milton's Paradiſe Loſt,	12*mo.*
——His Cato, Campaign, and Roſamund,	12*mo.*
BUlſtrode's Memoirs of K. Charles I. and II.	8*vo.*
Blackmore (Sir Richard) Pr. Arthur, a Poem,	12*mo.*
——His Job, a Poem,	12*mo.*
——His Poem on the Creation,	12*mo.*
Bellini's Mechanical Account of Fevers,	8*vo.*
Bayle's Critical and Hiſt. Dictionary in 4 Vol.	*Fol.*
Boyer's French and Engliſh Dictionary,	8*vo.*
Brown's Juſtin in Engliſh,	12*mo.*
Boulton's Syſtem of rational and practical Surgery,	8*vo.*
——3 Treatiſes of the Gout, King's Evil and French Diſeaſe,	8*vo.*
Boetius of the Conſolation of Philoſophy, tranſlated by the Lord Viſc. Preſton, during his Confinement in Newgate,	12*mo.*
Boyle's Theological Works abridged, with his Life, giving a large Account of his Philoſophical Works, in 3 Vol.	8*vo.*
Belcarras (Earl) Account of Scotland at the Revolution,	8*vo.*
Barrow, of Contentment, Patience, and Reſignation to the Divine Will,	12*mo.*
Buchanani Epiſtolæ,	8*vo.*
Beveridge (Bp.) his Vindication of the old Tranſl. of the Pſalms,	12*mo.*
——His Theſaurus Theologicus, 4 Vol.	8*vo.*
——His Private Thoughts, in 2 Volumes with Cuts,	8*vo.*
——His Expoſition of the 39 Articles,	*Folio* and 8*v*

——Neceſſity of publick Prayer, and frequent Communion, in *8vo.* and *12mo.*
Barrow's Works, 2 Vol. —— —— *Folio.*
Bibliotheca Biblica, or a Commentary on the Bible, publiſhed Monthly, —— —— —— *4to.*
Biſſe (Dr.) his Sermons on the Com. Prayer, —— *8vo.*
Blackall (Bp.) his Sermons publiſhed by himſelf, Vol. the 2d. *8vo.*
Beza's Lat. Teſt. —— —— —— —— *12mo.*
Brown's Spelling Book, —— —— —— *8vo.*
Boyſe's Expoſition of the 39 Articles, —— —— *Folio.*
Bloom's Hiſtory of the Bible, —— —— *4to.*
Burnet (Bp.) his Sermon's, with an Eſſay towards a New Book of Homilies, wrote at the Requeſt of A. Bp. Tillotſon, —— *8vo.*
Biſſe's Art of Engliſh Poetry in 4 Vol. being a complete Common Place Book to the Works of our moſt eminent Poets, -- *12mo.*
Bridle for the Tongue, —— —— —— *8vo.*
Blunt's Eſſays, —— —— —— —— *8vo.*
Convenient Prayer Book for private and family Uſe, by the Author of the Clergy-man's Companion in viſiting of the Sick, *8vo.*
Complete Hiſt. of Magick, Witchcraft and Sorcery, —— *12mo.*
Curſe of Popery and Popiſh Princes to England, demonſtrated from the Debates of Parliament relating to the Excluſion of James Duke of York, —— —— —— *8vo.*
Catechumenorum Ductor, collected from the Writings of the beſt Catechiſts, —— —— *12mo.*
Cambray (A. Bp.) of the Exiſtence of God, —— *12mo.*
Chronicon Pretioſum, or an Account of Engliſh Money, the Price of Corn, &c. for the laſt 600 Years.
Culpeper's Engliſh Phyſician, —— *12mo.*
——His Diſpenſatory, —— —— *12mo.*
——His Midwifery, —— —— *12mo.*
——His School of Phyſick, —— —— *8vo.*
Clark's Body of Divinity, conſonant to the Doctrine of the Church of England, 2 Vol. —— —— —— *8vo.*
Cole's Latin and Engliſh Dict. —— —— *8vo.*
Clerici Logica, —— —— —— *12mo.*
Chillingworth's Works, —— —— *Folio.*
Cæſaris Comment. Notis Delph. —— —— *8vo.*
——Idem, without Notes, —— —— *12mo.*
Country Gentleman's Vade Mecum, —— —— *12mo.*
Continuation of the Turkiſh Spy, —— —— *12mo.*
Collection of Tracts, wrote in Defence of the Church of England, recommended by Dr. Hickes. —— —— *8vo.*
Collection of Divine Hymns and Poems, by the moſt eminent Hands; publiſhed by Mrs. Singer.
Complete Sports-man, with all the Laws relating to the Game, *12mo.*
Complete Diſtiller, —— —— —— *8vo.*
Complete Clerk, —— —— —— *8vo.*

Cowell's Interpreter, ——— ——— *Folio.*
Cozens (Bp.) his Devotions, ——— ——— 12*mo.*
Collections of Tryals, 4 Vol. ——— ——— *Folio.*
Congreve's Works in 3 Vol. ——— ——— 12*mo.*
Clarendon's Hiſtory of the Rebellion in 6 Vol. ——— 8*vo.*
———The ſame in large Paper, ——— ——— 8*vo.*
Collection of Novels and Tales, written by that celebrated Wit of France, the Counteſs D'Anois, in 2 Vol. now firſt tranſlated into Engliſh by ſeveral Hands. 12*mo.*
Careleſs Husband, a Comedy, by Mr. Cibber. 12*mo.*
Chamberlain's State of Great Britain, ——— ——— 8*vo.*
Cowley's Works, ——— ——— ——— 12*mo.*
Clark's Concordance to the Holy Bible, ——— 12*mo.*
Chale's Euclid, ——— ——— ——— 8*vo.*
Critical Hiſtory of the Doctrines and Worſhip, both Good and Evil, from Adam to our Saviour Jeſus Chriſt. Giving an Account of all the Idolatries of the antient Pagans, with the State of the Jewiſh Church during that Period, by the learned Mr. Jurieu in 2 Vol. in 8*vo.*———N. B. Theſe 2 Vol. with Dean Prideaux's Connection, are the beſt Account of Eccleſiaſtical Hiſtory from Adam to our Saviour's Time, ——— ——— 8*vo.*
Court Tales, or the Amours of the preſent Nobility, with a complete Key, ——— ——— ——— 8*vo.*
Caſtalio's Kempis cum Figuris, ——— ——— 12*mo.*
Cunn of Fractions, ——— ——— 8*vo.*
Theatrum Scotiæ: Containing Views of the moſt remarkable Buildings in Scotland.

DAvenant (Dr.) his Report to the Commiſſioners of Trade, &c. ——— ——— ——— 8*vo.*
D'aſſigny againſt the Anabaptiſts, ——— ——— 12*mo.*
Devout Chriſtian's Daily Exerciſe, ——— ——— 12*mo.*
Donne's Poems on ſeveral Occaſions, ——— 12*mo.*
Dryden's Plays 6 Vol. ——— ——— 12*mo.*
———His Miſcellanies 6 Vol. ——— 12*mo.*
———Virgil in 3 Vol. ——— ——— 8*vo.*
———His Tranſlation of Ovid's Art of Love, with Cuts. 12*mo.*
———Juvenal, ——— ——— 12*mo.*
Devil on two Sticks, ——— ——— 12*mo.*
Diſtreſſed Mother, a Tragedy, by Mr. Philips, ——— 12*mo.*
Devout Communicant exemplified in his Behaviour, before, at, and after receiving the holy Sacrament, ——— 12*mo.*
Diſcourſe of God's Fore-knowledge and Man's Free-agency, wherein their ſeeming Oppoſition is reconciled, &c. 4th Edition.
Diſpenſary a Poem in 6 Cantos, by Sir Sam. Garth, with a compl. Key.
Daventer's Art of Midwifery improved, ——— 8*vo.*
Drelincourt of Death, ——— ——— 8*vo.*
Dugdale's Monaſticon Anglicanum in Engliſh, adorned with above one hundred Cuts of the moſt celebrated Religious Houſes, *Fol.*
Divine Breathings, ——— ——— 12*mo.*

Diodorus the Sicilian, his Hiſtorical Library in Engliſh, containing the Antiquities of Europe, Aſia, Africa, and Greece, &c. — *Folio.*
Denham (Sir John) his Works, in ——— 12*mo.*
An exact Deſcription of the total Eclipſe of the Moon, *Auguſt* 29, 1718.
Entertainer, containing Remarks on Men, Manners, Religion, Policy, &c. ——— ——— ——— 12*mo.*
Eraſmi Colloquia Notis Binaldi, ——— ——— 12*mo.*
The Effigies of His Majeſty King *GEORGE*, curiouſly engraven from Sir *Godfrey Kneller*'s Painting. Together with the late Mr. Secretary *Addiſon*'s Poem to Sir *Godfrey Kneller*, occaſioned thereby.
Engliſh Expoſitor, ——— ——— ——— 12*mo.*
Euſebius's Eccleſiaſtical Hiſtory in Engl. ——— *Folio.*
Etheridge's Plays, ——— ——— 12*mo.*
Echard's Eccleſiaſtical Hiſtory, Being a Continuation of Dean Prideaux's Connexion, ——— ——— *Folio.*
———His Hiſtory of England, ——— ——— *Folio.*
———His Roman Hiſtory, 5 Vol. ——— 8*vo.*
———His Claſſical Dictionary, ——— ——— 12*mo.*
Fontenelle's Dialogues of the Dead, ——— 8*vo.*
The Feaſt of Divine Love, ——— ——— 12*mo.*
Fair Warnings to a careleſs World, giving an Account of the Behaviour of the late E. of Rocheſter, and other remarkable Penitents, adorned with Cuts, 3d Edit. ——— 12*mo.*
A Funeral Gift, or a Preparation for Death, &c. ——— 12*mo.*
Great Importance of a religious Life, ——— 12*mo.*
Grammont (Count) his Memoirs of the Court of England, with a complete Key, ——— ——— 8*vo.*
Gay's Shepherds Week, in 6 Paſtorals, ——— 8*vo.*
———Hoop-Petticoat, a Poem.
Gerhard's Meditations, ——— ——— 12*mo.*
Gregory's Opticks, ——— ——— 8*vo.*
German Doctor, 2 Vol. ——— ——— 12*mo.*
Gentleman's Jockey, ——— ——— 8*vo.*
Goodman's Penitent Pardoned, ——— ——— 8*vo.*
———Winter Evenings Conference, ——— 8*vo.*
———Golden Rule, ——— ——— 8*vo.*
———Sermons, ——— ——— 8*vo.*
———Old Religion, ——— ——— 12*mo.*
———Compaſſionate Enquiry, ——— ——— 8*vo.*
Gregory's Nomenclatura, ——— ——— 8*vo.*
———Etymologicum Parvum, ——— ——— 8*vo.*
Greenwood of Courts, ——— ——— 8*vo.*
Guardians in 2 Vol. ——— ——— 12*mo.*
Gr. Teſt. with Marginal Notes, ——— 8*vo.*
Gibſon's Anatomy of Human Bodies Epitomiſed, with Cuts, 8*vo.*
Gedde's Tracts in 3 Vol. ——— ——— 8*vo.*

HOpkins's Works, *Folio*.
Hiſtory of England in 3 Vol. *Folio*
Hatton's Pſalter, 12*mo*.
Hammond's Devotions, 12*mo*.
Heraclitus Ridens, a Dialogue, &c. 2 Vol. 12*mo*.
Hopkins (Bp.) his Works, *Folio*.
Hope's complete Fencing Maſter with Cuts, 8*vo*.
———Swordſman's Vade Mecum, 8*vo*.
Hiſtory of the Revolutions of Sweden, by Abbot Vertot, 8*vo*.
———Of the Revolutions of Rome, by the ſame Author, 8*vo*.
———Of the Turks, 4 Vol. 8*vo*.
Hartland's Spelling Book, 12*mo*.
Hawksbee's Phyſico Mechanical Experiments, adorned with Cuts, the 2d Edition with large Additions, 8*vo*.
Hudibras, adorned with Cuts, 8*vo*. and 12*mo*.
Homer Notis Sylvani, 12*mo*.
Hiſtory of Nature, emblematically expreſſed in near one Hundred Folio Copper Plates, wherein are alſo repreſented all the Operations, Faculties and Paſſions of the Mind, according to the Manner of the moſt celebrated Poets and Philoſophers, deſigned and engraved by the beſt Artiſts, with an Explanation at large under each Figure, *Folio*.
Hiſtory of the Preſs-Yard, 8*vo*.
Hickes (Dr.) his 3 ſhort Treatiſes in Defence of the Prieſthood and true Rights of the Church, in Anſwer to a Book falſly call'd, the Rights of the Chriſtian Church, 8*vo*.
———His Sermons on ſeveral Occaſions in 2 Vol. 8*vo*.
Hill (A. Deacon) his Anſwer to the Rights of the Church. 8*vo*.
———Of valid and invalid Baptiſm, 8*vo*.
———Of Sacerdotal Remiſſion, 8*vo*.
———His Harmony, 8*vo*.
Hogarth's Grammar Diſputations, 8*vo*.
Hoadly (Bp.) his Meaſures of Obedience enquir'd into, and diſproved by Mr. Spinckes, 8*vo*.
Howel (Dr.) his compendious Hiſtory of England adorned with Cuts. 8*vo*.
Hiſtorical Account of Tryals, Chronologically digeſted, in 2 Vol. in 12*mo*.
Dr. *Halley's* Deſcription of the Paſſage of the Shadow of the Moon over *England*, in the total Eclipſe of the Sun, *April* 22, 1715.
———His Deſcription of the paſſage of the Shadow of the Moon, as it was obſerved in the ſaid Eclipſe; with the Tranſit of the Shade, as it will paſs over *England* in the next great Eclipſe of the Sun, that will happen in *Anno* 1724.
A *Hexagon*, or Scheme, explaining the Terms uſed in Fortification.
JOhnſon's Noctes Nottinghamicæ, or Curſory Objections againſt the Syntax of the common Grammar, 8*vo*

Juſtice's Vade Mecum.
Journey thro' France, —— —— *8vo.*
Jacob's Eſſays on ſeveral Subjects, —— —— *12mo.*
KEnnet (Bp.) his Sermon on the 30th of January, —— *8vo*
Kettlewell's Works in 2 Vol. in —— *Folio.*
——Practical Believer, —— —— *8vo.*
——His Meaſures of Obedience, —— —— *8vo.*
——His Worthy Communicant, —— —— *8vo.*
——His Nine Sermons, with an Account of his Life by Robt. Nelſon, Eſq; —— —— —— *8vo.*
——All his other Works, —— *4to, 8vo,* and *12mo.*
Keay's Practical Meaſurer's Pocket Companion.
LAndlord and Tenants Law, —— —— *12mo.*
Lex Londinenſis, —— —— —— *8vo.*
Lady's Library in 3 Vol. —— —— *12mo.*
Life of Pythagoras, with his Golden Verſes, by N. Rowe, Eſq; *8vo.*
Love and Religion, demonſtrated in the Martyrdom of Theodora and Didymus, —— —— *12mo.*
Love betrayed, or the unexpected Wife, a Novel, —— *12mo.*
Love Letters between a Nobleman and his Siſter, —— *8vo.*
Lucas's Practical Chriſtianity, —— —— *8vo.*
——Enquiry after Happineſs, —— —— *8vo.*
——Chriſtian Thoughts, —— —— *12mo.*
Lowthorp's Abridgment of the Philoſophical Tranſactions, 3 Vol. *4to.*
Lucian's Works in Engliſh, in 4 Vol. tranſlated by Mr. Dryden and other eminent Hands, —— —— *8vo.*
Life of K. Charles by Mr. Larrey, Hiſtoriographer to the K. of Pruſſia, in 2 Vol —— —— *8vo.*
Life of A. Bp. Tillotſon, in —— *Folio* and *8vo.*
Life of A. Bp. Whitgift, —— —— *Folio.*
Life of Mr. Kettlewell, —— —— *8vo.*
Langallery's Memoirs of the laſt War, —— *8vo.*
Livy's Roman Hiſtory in Engliſh, —— —— *Folio.*
Lock's Works in 3 Vol. —— —— *Folio.*
——His Paraphraſe on St. Paul's Epiſtles, —— *4to.*
——His Treatiſe concerning Government, —— *12mo.*
——Of Education, —— —— *12mo.*
——His familiar Letters, —— —— *8vo.*
Littleton's Dictionary, —— —— *4to.*
Life of Sir. W. Temple, —— —— *8vo.*
Leſtrange's Æſop, 2 Vol. —— —— *8vo.*
Life and ſtrange ſurpriſing Adventures of Robinſon Cruſo, in 2 Vol. 6th Edition. —— —— —— *8vo.*
Ludlow's Memoirs of the Civil Wars in 3 Vol. —— *8vo.*
Lockhart's Memoirs of Scotland, with a complete Key, —— *8vo.*
Life and Adventures of Sign. Roſelli, adorned with Cuts, *8vo.*
Lowth on Iſaiah, —— —— *4to.*
Lemery's Chymiſtry, —— —— —— *8vo.*

MAttaire's Edition of the Claſſics, in 21 Vol. ——— 12*mo.*
——His Gr. Teſtament, ——— 12*mo.*
Marten's Deſcription of the Weſtern Iſlands of Scotland,——— 8*vo.*
Memoirs of the Church of Scotland, ——— 8*vo.*
C. of Morton's Devotions, ——— ——— 24*o.*
Memoirs of North-Britain in Anſwer to Lockart's Memoirs, 8*vo.*
Mead's Conſtruction and Uſe of the Globes, ——— 8*vo.*
Memorable Things of Socrates, ——— ——— 8*vo.*
Medulla Hiſtoriæ Anglicanæ, with Cuts, ——— 8*vo.*
Montfaucon's Travels into Italy, ——— ——— 8*vo.*
Marſhall (Dr.) his Tranſlation of St. Cyprian's Works,——— *Folio.*
———His Sermon on the Death of Q. Anne, 4th Edit. 8*vo.*
———His Penitential Diſcipline of the Primitive Church, 8*vo.*
———His Sermon on the Death of Mr. Blundell, ——— 8*vo.*
———A regular Succeſſion in the Chriſtian Church aſſerted, in a Viſitation Sermon, ——— ——— 8*vo.*
Memoirs of Ireland from the Reſtoration to the Revolution, 8*vo.*
Maxwell's Diſcourſe concerning God. 12*mo.*
Moor (Bp. of Ely) his Serm. on ſeveral Occaſions, 2 Vol. 8*vo.*
Mr. Marſhall's Chronological Tables, reviſed by the late Bp. of Worceſter, ——— ——— ——— *Fol.*
Miſcellanea Antiqua, &c. by Mr. Oliphant, ——— 8*vo.*
Militia-Law, containing all the Laws relating to the Militia, 12*mo.*
Moral Books of the Old Teſtament, Paraphraſed, ——— 12*mo.*
Memoirs of the Life and Writings of Arthur Manwaring, Eſq; late Auditor of the Impreſt, ——— ——— 8*vo.*
Memoirs of D. Hamilton, ——— ——— 8*vo.*
Martialis in Uſum Delphini, ——— ——— 8*vo.*
NEW Manual of Devotions, ——— 12*mo.*
Nicholſii Hiſtoria Sacra in uſum Scholarum, ——— 12*mo.*
Nelſon's Great Duty of Frequenting the Chriſtian Sacrifice, 12*mo.*
Newton's (Sir Iſaac) Algebra, tranſlated into Engliſh by Mr. Raphſon, ——— ——— ——— ——— 8*vo.*
Needham's Hierocles, ——— ——— 8*vo.*
New General Atlas, printed on a Fine Elephant Paper, and adorned with Maps, ——— ——— *Fol.*
Norris's Miſcellanies, in ——— ——— ——— 12*mo.*
OGleby's Survey of the Roads of England, improved, very much Corrected, and made Portable, by John Senex, 4*to.*
Ovid's Metamorphoſis, Engliſh, 2 Vol. ——— 12*mo.*
———Epiſtles Engl. ——— ——— ——— 12*mo.*
———Art of Love with Cuts, ——— 12*mo.*
Ovidii Epiſtolæ Notis Delphini, ——— ——— 8*vo.*
PAtrick's Pſalms, ——— ——— 12*mo.*
——Paraphraſes in 2 Vol. ——— ——— 4*to.*
——Witneſſes to Chriſtianity, ——— ——— ——— 8*vo.*
——Grotius in Engliſh, ——— ——— 8*vo*

——Heart's Eaſe, ——— ——— 12*mo.*
——Devout Chriſtian, ——— ——— 12*mo.*
——Chriſtian Sacrifice, ——— ——— 12*mo.*
——Advice to a Friend, ——— ——— 12*mo.*
——Frequent Communion, ——— ——— 12*mo.*
——Of Repentance, ——— ——— 12*mo.*
——Of Prayer, ——— ——— 12*mo.*
——Help to young Beginners, ——— 24*o.*
Phillips's Engliſh Dictionary, ——— ——— *Fol.*
Poems on ſeveral Occaſions, by Mr. Pomfret, Author of the Choice, 12*mo.*
Plutarch's Lives and Morals, printed on an Elzevir Letter, 10 Vol. 12*mo.*
Puffendorff's Law of Nature and Nations, ——— *Fol.*
——Abridg'd in 2 Vols. ——— ——— 8*vo.*
Plautus's Comedies, done into Engliſh by Mr. Eachard, ——— 12*mo.*
Pitcairne (Dr.) his Works Engliſh, ——— 8*vo.*
Pietas Londinenſis: The preſent Eccleſiaſtical State of London, 12*mo.*
Peerage of England, 2 Vol. ——— ——— 8*vo.*
Plays in Pocket Volumes, written by Shakeſpear, Addiſon, Otway, Congreve, Southerne, Farqhuar, Steel, Etheridge, Cibber, Vanbrugh, Row, Dryden, Shadwell, Mountfort, ——— 12*mo.*
Poetæ minores, Gr. & Lat. ——— ——— 8*vo.*
Pills to purge Melancholy, 6 Vol. ——— 12*mo.*
Prideaux's Connection of the Old and New Teſtament, in *Fol.* and 8*vo.*
Puffendorff's Introduction to the Hiſtory of Europe, continued, 8*vo.*
Penkethman's Jeſts, ——— ——— 12*mo.*
Pearſon (Archdeacon) his Sermons on ſeveral Occaſions, preached in the Cathedral of York, ——— ——— 8*vo.*
Prior's Poems. ——— ——— ——— *Fol.*
Perſpective made eaſy, by Father Lamy, adorned with Cuts, 8*vo.*
Preſent State of the Britiſh Court, being an exact Liſt of all the Officers, Civil and Military, ——— ——— 8 *vo.*
Pictures of his Majeſty, and their Royal Highneſs the Prince and Princeſs, in Miniature, exquiſitely performed.
A Plan of the City of *Salisbury*, with a View of the *Cathedral*, and a Survey of the River *Avon*, from *Salisbury* to the Sea.
A Pocket *Atlas*, or a ſmall Set of Maps of the World, and its Quarters. Done according to the lateſt Obſervations.
Quincy, (Dr.) his Diſpenſatory, ——— ——— 8*vo.*
——His Phyſical Dictionary, ——— 8*vo.*
——His Anſwer to Dr. Woodward's State of Phyſick, &c. 8*vo.*
——His Tranſlation of Sanctorius's Aphoriſms, with large Explanations, the 2d Edition, with large Additions, ——— 8*vo.*
Quintus Curtius Delphini, ——— ——— 8*vo.*
Roſcommon's Works, ——— ——— 8*vo.*
Report of the Committee of Secrecy, by the Rt. Hon. R. Walpole, Eſq; ——— ——— *Folio* and 12*mo.*

Raphſon's Analyſis Æquationum, —— —— *4to.*
——Demonſtratio de Deo, —— —— *4to.*
Rawbone's Path to Liberty: Or the Method of Man's Redemption by the Lord Jeſus Chriſt, —— —— *8vo.*
The Retired Gardiner, being Dialogues between a Gentleman and a Gardiner, containing Rules for making and improving Gardens, with the Manner of planting and cultivating moſt kinds of Flowers, Plants, Shrubs, Underſhrubs, &c. formerly publiſhed by G. London, and Henry Wiſe, the 2d Edition, reviſed by Joſeph Carpenter, adorned with Cuts, —— —— *8vo.*
Robertſon's Hebrew Pſalter, —— —— 12*mo.*
Reeve's Tranſlation of the Apologies of Juſtin Martyr, Tertullian, Minucius Fœlix, and Vincentius Lirinenſis, in Defence of the Chriſtian Religion; with a Prefatory Diſſertation concerning the right Uſe of the Fathers, 2 Vols —— *8vo.*
Reflections on Ridicule, —— —— 12*mo.*
SAncroft (Abp.) his Sermons on ſeveral Occaſions, —— *8vo.*
Sandford's Genealogical Hiſtory of England, —— *Fol.*
Suetonius in Engliſh, —— —— 12*mo.*
Suetonius Delphini, —— —— *8vo.*
Selden's Table Talk, —— —— 12*mo.*
Salmon's Herbal, —— —— *Fol.*
Sacred Geography, in 6 Maps, very uſeful for the better underſtanding the Holy Bible.
Spinckes's ſick Man viſited, and furniſhed with Meditations and Prayers ſuitable to his Condition, for putting him in Mind of his Change, for ſupporting him under his Diſtemper, and preparing him for, and carrying him through his laſt Conflict with Death, —— —— —— *8vo.*
Stanyan's Account of Switzerland, —— —— *8vo.*
Supplement to Nelſon's Feſtivals, being a Companion for the Lord's Day, —— —— —— *8vo.*
Shuttleworth's Eſſay on a Comprehenſion, —— *8vo.*
Spectators in 8 Vols. —— —— 12*mo.*
Supplement to Dugdale's Monaſticon, 2 Vols. *Fol.* in the Preſs.
The Spaniſh Pole-cat; being the Adventures of Seigniora Rubina, —— —— —— 12*mo.*
Salmon's Country Phyſician, —— —— *8vo.*
——His Ars Anatomica, —— —— *8vo.*
Schrevelius's Lexicon, —— —— *8vo.*
Stanhope's St. Auſtin, —— —— *8vo.*
——His Thomas a Kempis, —— *8vo*, and 12*mo.*
Sir John Suckling's Works, containing his Plays, Poems, and Love-Letters, —— —— 12*mo.*
Swinden's Enquiry into the Nature and Place of Hell, —— *8vo.*
The *Solar Syſtem*: With the Orbits of the *Comets* and *Planets* belonging thereto: Deſcrib'd from Dr. *Halley*'s accurate Table of *Comets*, *Philoſoph. Tranſact.* Num. 297. founded on Sir *Iſaac Newton*'s Wonderful Diſcoveries. By *William Whiſton*, M. A.

Mr. *Senex*'s Thirty one new and accurate Maps, *viz*.

Europe,
Aſia,
Africa,
America, North and South.
Great Britain,
Ireland,
Ten *Spaniſh Provinces*,
Flanders,
Artois,
Hainault, with the Country about *Namur* and *Cambray*,
The Seven United Provinces,
France,
The Country about *Paris*,
Spain and *Portugal*.
Caſtile New and Old,
Italy,
Germany,
Denmark,
Sweden,
Poland,
Hungary,
Muſcovy,
Turkey in *Europe*,
Turkey with *Arabia* and *Perſia*.

Sacred Geography; contain'd in 6 Maps, *viz*.

1ſt. Shewing the Situation of *Paradiſe*, and the Country inhabited by the *Patriarchs*.

2d. The peopling of the World by the Sons of *Noah*, and the *Iſraelites* Journeying in the Wilderneſs.

3d. A Plan of the City of *Jeruſalem*: With a View of *Solomon*'s Temple, and all the ſacred Utenſils therein.

4th. The Holy Land divided into the Twelve Tribes of *Iſrael*, in which is exactly traced our Saviour's Travels.

5th. The Land of *Canaan*.

6th. The Travels of St. *Paul*, and the reſt of the Apoſtles. The whole very neceſſary for the better underſtanding of the Holy Bible.

TUrretin's Oration of compoſing Differences among Proteſtants, —— —— *4to*.
——His Oration of the different Fates of the Chriſtian Religion, *4to*
Tryal of the Duke of Norfolk, for attempting to marry Mary Queen of Scots, —— —— *8vo*.
Tartarian Tales, —— —— *12mo*.
Taylor, (Bp.) His holy Living and Dying, —— *8vo*.
——His Golden Grove, —— —— *12mo*.
——His Liberty of Prophecying, —— —— *8vo*.
——His Life of Chriſt, preparing for the Preſs, and adorned with CopperPlates, newly engraved and deſigned by the beſt Hands. *Fol*.
——Caſes of Conſcience, —— —— *Fol*.
——Doctrine of Repentance. —— *8vo*.
Sir Wm. Temple's Works, 2 Vols. —— —— *Folio*.
VIrgil, Notis Binaldi, —— —— *8vo*.
Vanbrugh, (Sir John) his Plays, viz. Relapſe, the provok'd Wife, Æſop in two Parts, the Confederacy, the falſe Friend, and the Miſtake, —— —— *12mo*.
Virgil in Uſum Delphini, —— —— *8vo*.
Uſher, (Archbp.) his Life and Letters, —— *Folio*.
Votes of the Houſe of Commons, 1715, 16, 17, 18, 19 —— *Fol*.

Univerſal Library, in 2 Vols. ——— ——— 8*vo.*

Vitruvius Britannicus: Or, The *Britiſh Architect*; containing the Plan, Elevation, and Sections of the regular Buildings, both publick and private, in *Great Britain*: With Variety of new Deſigns, in 200 large Folio Plates, engraven by the beſt Hands, and drawn either from the Buildings themſelves, or the Original Deſigns of the Architect. In two Volumes.

WHiſton's Aſtronomical Principles of Religion, with Cuts, 8*vo.*
——His Aſtronomical Lectures.
————His Elements of Euclid, with Tacquet's Comment.
————His Demonſtration of Sir Iſaac Newton's Philoſophy.
————His Account of the Meteor in March 1715-16.
————Ditto 1718-19.
————His Addreſs to the Princes of Europe.
————His two Letters to the Biſhop of London.
————His Letter to the E. of Nottingham.
————His Account of Dr. Sacheverell's Proceedings.
————His Paraphraſe on the 1ſt Epiſtle of St. John.
————His Origin of the Sabellian and Athanaſian Doctrines.
————His Calculation of the great Eclipſe of the Sun, *April* 22, 1715. With its Conſtruction for *London*, *Rome*, and *Stockholm.*
———His complete Account of the great Eclipſe of the Sun, *April* 22, 1715.
———His Scripture Politicks, addreſs'd to the Biſhop of Bangor.

Wingate's Arithmetick, with Shelly's Supplement. ——— 8*vo.*
Winchelſea, (Lady) her Poems on ſeveral Occaſions, ——— 8*vo.*
Wit's Common Wealth, ——— ——— 12*mo.*
Wake, (Archbp.) his Sermons on ſeveral Occaſions, ——— 8*vo.*
Wiſe's Sermons on ſeveral Occaſions, ——— 8*vo.*
Wilkins, (Bp.) of Prayer and Preaching, ——— 8*vo.*
Whitby on the New Teſtament, 2 Vols. ——— *Folio.*
——His Additions, with Examen Millii, ——— *Folio.*
Wells's Dionyſius de Situ Orbis, cum Tabulis, ——— 8*vo.*
Wentworth's Office of Executors, ——— 8*vo.*
Ward's England's Reformation, 2 Vols, ——— 12*mo.*
Warder's Monarchy of Bees, being a new Diſcovery and Improvement of thoſe wonderful Creatures, 4th Edition, ——— 8*vo.*
Ward's Clavis Uſuræ, or Key to Intereſt, both Simple and Compound, ——— ——— ——— 12*mo.*
Wilſon's Commentary on the Revelations, giving an Account of the Accompliſhment of ſeveral Scripture Prophecies, — 8*vo.*
Way to be wiſe and wealthy, or the Excellency of Induſtry and Frugality, ——— ——— 8*vo.*
Wilkinſon's Office of Sheriffs, ——— ——— 8*vo.*
Watſon's Clergyman's Law, ——— ——— 8*vo.*

YOung's Sermons, 2 Vols. ——— ——— 8*vo.*

BOOKS *lately Printed*, &c.

THE Works of the Right Reverend Father in God, Dr. *William Beveridge*, late Lord Biſhop of St. *Aſaph*. Containing all his Sermons, as well thoſe publiſhed by himſelf, as thoſe ſince his Death. Now firſt correctedly printed, in two Volumes, *Folio*. With a Preface, giving ſome Account of the Author, and his Writings. As alſo three uſeful Tables. I. The Contents of the ſeveral Diſcourſes. II. Of the Texts of Scripture occaſionally explain'd. III. An Alphabetical Index to the Whole.

—— His private Thoughts: In Two Parts complete. Part I. Upon Religion, digeſted into Twelve Articles, with practical Reſolutions thereupon. Part II. Upon a Chriſtian Life; or neceſſary Directions for its Beginning and progreſs upon Earth, in order to its final perfection in the Beatifick Viſion. The Tenth Edit. — 12*mo*.

Diſcourſes concerning the ever-bleſſed Trinity, viz. I. *The Folly of* Atheiſm. II. *The Name, Nature, and Being of God.* III. *The Trinity in Unity.* IV. *Baptiſm in the Trinity.* V. *The* Word *ever God.* VI. *Jeſus Chriſt equal with God.* VII. *Jeſus Chriſt the Image of God.* VIII. *The Angelical Worſhip of Jeſus Chriſt.* IX. *The Word made Fleſh.* X. *The Spirit of Truth a divine Perſon.* XI. *The Holy Ghoſt the Paraclete.* XII. *The Puniſhment of Apoſtacy.* Uſeful for all, but eſpecially the ſenſible Laity. By the Author of *The Divine Right of Epiſcopacy*. —— —— —— 8*vo*.

Chriſtian Converſation; In Six Dialogues. I. *Between a doubting Chriſtian, and one more confirmed, about* Aſſurance. II. *Between the ſame Perſons about* Mortification. III. *Between* Eutocus *and* Fidelius, *about* Natural Things Spiritualized. IV. *Between* Simplicius *and* Conſocius, *about* Union. V. *Between* Thlipſius *and* Melandrus, *about* Afflictions. VI. *Between* Athanaſius *and* Biotes, *about* Death. By a private Gentleman. —— —— 12*mo*.

The *Religious Philoſopher*: or, The right Uſe of contemplating the Works of the *Creator*. I. *In the wonderful Structure of Animal Bodies, and in particular* M A N. II. *In the no leſs wonderful and wiſe Formation of the Elements, and their various Effects upon Animal and Vegetable Bodies. And,* III. *In the moſt amazing Structure of the Heavens, with all its Furniture.* Deſigned for the *Conviction* of *Atheiſts* and *Infidels*. Throughout which all the late Diſcoveries in *Anatomy*, *Philoſophy*, and *Aſtronomy*; together with the various Experiments made uſe of to illuſtrate the ſame, are moſt copiouſly handled by that learned *Mathematician*, Dr. *Nieuwentyt*. Tranſlated from the Original, by *John Chamberlaine*, Eſq; *F.R.S.* To which is prefixed, *A Letter to the Tranſlator*, by the Reverend *J. T. Deſaguliers, LL. D. F. R. S.* and Chaplain to his Grace the Duke of *Chandois*. Adorn'd with Cuts. In three Volumes. The 3d Edition. 8*vo.*

The Farriers New Guide : containing, *Firſt*, The Anatomy of a Horſe, being an exact and compendious Deſcription of all his parts; with their Actions and Uſes, illuſtrated with Figures curiouſly engraven on Copper-plates. *Secondly*, An Account of all the Diſeaſes incident to *Horſes*, with their *Signs*, *Cauſes*, and *Methods* of *Cure* ; wherein many Defects in the Farriers Practice are now carefully ſupplied, their Errors expoſed and amended, and the Art greatly improved and advanced, according to the lateſt Diſcoveries. The whole interſpers'd with many curious and uſeful Obſervations concerning *Feeding* and *Exerciſe*, &c. by W. Gibſon, ——— 8*vo.*

The Farriers Diſpenſatory : In Three Parts, containing, I. A Deſcription of the medicinal Simples, commonly made Uſe of in the Diſeaſes of Horſes, with their Virtues, and Manner of Operation, diſtributed into proper Claſſes, *&c.* II. The Preparations of Simples, *Vegetable*, *Animal*, and *Mineral* ; with an Explanation of the moſt uſual Terms, both in the *Chymical* and *Galenical Pharmacy*. III. A Number of uſeful Compoſitions and Receipts, ſuited to the Cure of all Diſeaſes, never before publiſhed ; as alſo thoſe of greateſt Account from *Solleyſel*, *Ruini*, *Blundevill*, and other moſt celebrated Authors, digeſted under their proper Heads of *Powders*, *Balls*, *Drinks*, *Ointments*, *Charges*, *&c.* The proper Method of compounding and making them. With many other uſeful Obſervations and Improvements, tending to their right Adminiſtration. To which is alſo added, A complete Index of all the *Medicines* contained in the Book, whether *Simple* or *Compound*, with a Table of Diſeaſes pointing to the Remedies proper in each Malady. By the ſame Author. ——— 8*vo.*

Mathematical Elements of Natural Philoſophy confirmed by Experiments, or an Introduction to Sir *Iſaac Newton*'s Philoſophy. Writen in *Latin* by *William-James*'s *Graveſande*, Doctor of Laws and Philoſophy, Profeſſor of Mathematicks and Aſtronomy at *Leyden*, and F. R. S. of *London*. Tranſlated into *Engliſh* by *J. T. Deſaguliers*, LL. D. F. R. S. and Chaplain to his Grace the Duke of *Chandois*. 8*vo.*

Phyſico-Mechanical Experiments on various Subjects. Containing an Account of ſeveral ſurprizing Phænomena touching Light and Electricity, producible on the Attrition of Bodies. With many other remarkable Appearances, not before obſerv'd. Together with the Explanations of all the Machines, (the Figures of which are curiouſly engrav'd on Copper) and other Apparatus us'd in making the Experiments.

periments. To which is added a Supplement, containing ſeveral New Experiments not in the former Edition. The *Second Edition.* By *F. Hauksbee*, F. R. S. —— —— 8*vo.*

A Treatiſe of the Motion of Water, and other Fluids: With the Origin of Fountains and Springs, and the Cauſe of Winds. In which Treatiſe, the Manner of Levelling and Conducting Rivers, in Order to make them Navigable; the making of Aqueducts for the Supply of Gentlemens Seats; the whole Art of contriving and making Jetts of Water for Fountains; and the Manner how to proportion the Strength of Pipes for conveying Water from any Height, are plainly demonſtrated from the Laws of *Hydroſtaticks*, by above 100 curious Experiments. Written originally in *French*, by the Learned *M. Marriotte*, Member of the *Royal Academy* at *Paris*. And Tranſlated into *Engliſh*, with ſeveral Annotations for Explaining the doubtful Places, By *J. T. Deſaguliers*, LL. D. F. R. S. Chaplain to his Grace the Duke of *Chandois*. —— 8*vo.*

Trigonometry Improv'd, and the Projection of the Sphere, made eaſy. Teaching the Projection of the Sphere Orthographick, and Stereographick: As alſo, Trigonometry Plain and Spherical; with plain and intelligible Reaſons for the various and moſt uſeful Methods both in Projection and Calculation; with the Application of the whole to Aſtronomy, Dialling, and Geography. By *H. Wilſon.* 12*mo.*

The *London* Accomptant: Or, Arithmetick in all its Parts. *Viz.* In whole Numbers and Fractions, Vulgar and Decimal, with the Extraction of the Square and Cube Root, not only taught, but the Reaſons of the Operations demonſtrated, and made intelligible to all Capacities. By the ſame Author. —— 12*mo.*

The Poetical Works of Mr. *John Milton*, in 2 Vol. Containing, I. *Paradiſe Loſt*; with Notes by the late Rt. Hon. Mr. Secretary *Addiſon.* II. *Paradiſe Regained:* To which is added *Samſon Agoniſtes*; And Poems on ſeveral Occaſions; with a Tractate of Education. Adorned with Cuts. —— —— 12*mo.*

Geodæſia; or the Art of Surveying and Meaſuring of Land made eaſie. Shewing, by plain and practical Rules, how to Survey, Protract, Caſt up, reduce or divide any Piece of Land whatſoever; with new Tables for the eaſe of the Surveyor in reducing the Meaſures of Land. Moreover, a more facile and ſure Way of Surveying by the Chain, than has hitherto been Taught. As alſo how to lay out new Lands in *America* or elſewhere: To make a perfect Map of a River's Mouth or Harbour; And ſeveral other Things never yet Publiſh'd in our Language. By *John Love.* The Third Edition, with Additions. —— 8*vo.*

The Life, Adventures, and Pyracies, of the Famous Captain *Singleton*: Containing an Account of his being ſet on Shore in the Iſland of *Madagaſcar*, his Settlement there, with a Deſcription of the Place and Inhabitants: Of his paſſage from thence, in a Paraguay, to the main Land of *Africa*, with an Account of the Cuſtoms and manners of the People: His great Deliverance from the barbarous Natives and wild Beaſts: Of his meeting with an *Engliſhman*, a Citizen of *London* among the *Indians*, the great Riches he acquired, and his Voyage Home to *England*: As alſo Captain *Singleton*'s Return to Sea, with an Account of his many Adventures and Pyracies with the famous Capt. *Avery* and others. 8*vo*.

The Hiſtory of the Wars, of his late Majeſty *Charles* XII. King of *Sweden*, from his firſt Landing in *Denmark*, to his Return from *Turkey* to *Pomerania*. The Second Edition. With a Continuation to the Time of his Death. By a *Scots* Gentleman in the *Swediſh* Service. ——— ——— ——— 8*vo*.

The Baronettage of England, being an Hiſtorical and Genealogical Account of Baronets, from their firſt Inſtitution in the Reign of K. James I. with their Coats of Arms and Creſts Engraved and Blazoned. 2 Vol. ——— ——— 8*vo*.

Memoirs of a Cavalier; or a Military Journal of the Wars in Germany, and the Wars in England, from the Year 1632 to 1648. Written threeſcore Years ago by an Engliſh Gentleman, who ſerved in the Army of Guſtavus Adolphus the Glorious K. of Sweden till his Death, and after that in the Royal Army of K. Charles the Firſt. ——— ——— ———8*vo*.

Cruſoe's Miſcellanies, wrote during his Solitude in the Iſland, with his Viſion of the Angelick World, to which is prefix'd a Frontiſpiece, repreſenting the moſt remarkable Incidents of his Life. ——— ——— ——— 8*vo*.

Gardening inprov'd; containing I. The Clergyman's Recreation; ſhewing the Pleaſure and Profit of the Art of Gardening. Wherein is treated, 1. Of preparing the Ground for Planting and Sowing. 2. Of the Method of planting Fruit-Trees in Gardens. 3. Of the moſt agreeable Diſpoſition for a Garden. 4. Of Nurſeries. 5. Of Pruning. 6. Of Grafting and Inoculating. 7 Of the proper Diſpoſition of Trees againſt a Wall, the beſt Kinds of each, their Order and Time of ripening, &c. II. *The Gentleman's Recreation*: Or, The Second Part of the Art of Gardening improved. Containing ſeveral New Experiments and curious Obſervations relating to Fruit Trees; particularly a new Method of Building Walls with Horizontal Shelters. Illuſtrated with Copper

Plates. Both written by *John Lawrence*, M. A. Rector of *Telvertoft* in *Northamptonſhire*. III. *The Lady's Recreation*: Or, The Art of Gardening farther Improved. Containing the beſt Ways of propagating all Sorts of Flowers, Flower-Trees and Shrubs, *&c.* The moſt commodious Methods for Erecting Green-Houſes, *&c.* Of Plantations in Avenues, Walks, Wilderneſſes, *&c.* With the Gardener's compleat Calendar: Or, The Art of managing both the *Fruit-Garden* and *Kitchen-Garden* every Month in the Year. By *Charles Evelyn*, Eſq; To which is added, A Letter to the Author, containing ſome curious Obſervations concerning Variegated Greens, by *J. Lawrence*, M. A. Rector of *Telvertoft* in *Northamptonſhire*. 8vo.

An exact Deſcription of all the Fixed Stars, to which the Moon or Planets can at any Time apply, carefully laid down in two large Sheets, from the *Britiſh* Catalogue of Stars lately publiſh'd; being of Uſe to all Lovers of Aſtronomy, and particularly to ſuch, as may be deſirous to put in practice the Art of finding the Longitude at Sea by Help of the Moon. By *Edm. Halley*, L. L. D. Savilian Profeſſor of Geometry at *Oxford*, F. R. S.

A Proſpect of Mount *Athos*, called *Monte Santo*, or the *Holy Mountain*. *N. B.* This moſt famous Mountain is called *Athos*, from *Athon* a Son of *Neptune*, ſituate in *Macedonia*, lying directly Weſt from *Lemnos*, and ſo high, that tho' it be 700 Furlongs Deſcent, yet a little before the Setting of the Sun, it caſts a Shadow over the greateſt Part of the Iſland: It is above three Days Journey in Length, and half a Day's Journey over, the Top whereof reſembles two Pyramids; and what is prodigious, a vaſt Torrent of moſt clear Water flows from the Point of the Mountain. It is inhabited by the Clergy of the *Greek* Church, ſubject to the Patriarch of *Conſtantinople*, in Number about ſix Thouſand, who never eat Fleſh, and great part of the Year eat no Fiſh; they never marry, are moſt exact in obſerving the ſacred Inſtitutions of the Church of *Chriſt*, of which this is a glorious Branch. The Clergy of this Place, for their Strictneſs of Life, and pure Primitive Piety, are greatly reverenced and relieved by many Chriſtian Princes: In their Monaſteries they have preſerved many ancient and curious Manuſcripts. To conclude, they are at this Day very zealous Labourers in the Vineyard of Chriſt. Done from the original Drawing, brought over by the Reverend *Gennadius*, *Archimandrite* of *Alexandria*, now in *London*.